ALTERNATIVES FOR BENEFICIAL USE OF DREDGED MATERIAL, LAGUNA MADRE, TEXAS

Prepared for:
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CONVERSION FACTORS

Units (alphabetical)	Multiply by:
Centimeters to inches	0.3937
Cubic meters to cubic feet	35.31
Cubic meters to cubic yards	1.308
Hectares to acres	2.471
Kilometers to miles	0.6214
Meters to feet	3.281
Square kilometers (km^2) to square miles	0.3861

1. INTRODUCTION

1.1 PURPOSE OF STUDY

The Laguna Madre is an environmentally sensitive, ecologically productive coastal water body located behind Padre Island, between Corpus Christi and Brownsville, Texas. This natural system has been altered by human activities, including the dredging of the Gulf Intracoastal Waterway (GIWW). Figure 1-1 is a simplified location map of the project area. Figure 1-2, located in a map pocket at the back of this report, shows additional detail in the project area, using USGS 1:250,000 scale topographic maps.

An Interagency Coordination Team (ICT), consisting of federal and state agencies, has been formed by the Galveston District of the U.S. Army Corps of Engineers to identify environmental concerns regarding the GIWW in the Laguna Madre. The ICT is also to contribute to a Dredged Material Management Plan and an Environmental Impact Statement for this segment of the GIWW.

The U.S. Environmental Protection Agency (EPA) is a member of the ICT, and in addition has extensive responsibilities for regulating ocean dumping of dredged materials under the Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA), as amended. In support of the ICT effort, EPA Region 6 issued Work Assignments 1-05 and 2-04 (Contract No. 68-D6-0067) to its level-of-effort contractor, Lee Wilson and Associates, and also funded laboratory analyses through the Galveston District, U.S. Army Corps of Engineers (USACE).

Collectively, the work done on behalf of EPA has provided two contributions to the Dredged Material Management Plan and Environmental Impact Statement.

- Most of the budget resources provided by EPA were used to sample and characterize sediment and water at 26 locations along the GIWW, and in reference areas in the vicinity of two offshore sites where dredged materials from navigation channels are deposited. (These are Ocean Dredged Material Disposal Sites, or ODMDS.) The results of the dredged material characterization are presented in LWA (1998), a separate report.

- The remaining effort involved preparation of this report, which is an environmental overview of alternatives for beneficial use of material dredged from the GIWW of the Laguna Madre.

1.2 SCOPE OF STUDY

This study was narrowly focused, as follows.

- Study area. The geographic area of study is the Laguna Madre-Padre Island ecosystem. Beneficial uses that may occur substantially inland, or offshore, have not been considered.
- Categories of beneficial use. Table 1-1 lists general categories of beneficial use previously identified by USACE and EPA. Reflecting guidance from EPA and the focus of ICT interests, this study considered only uses that would directly benefit the Laguna Madre ecosystem -- in effect the first two categories on the table. Other potential uses, such as the building of dry land for human purposes, or using material to improve grazing lands, were considered outside the scope of this initial study. Thus, as an example, beneficial use to create or modify dredged material islands was considered because of its potential to provide habitat for colonial nesting birds, not because the islands might provide building sites for coastal cabins.
- Quantification of beneficial use. No effort was made to quantify the amount of beneficial use that might be achieved. The possibility exists that all the beneficial uses discussed here could be implemented, and there would remain dredged material that required non-beneficial placement.
- Non-beneficial disposal. At EPA's direction, one non-beneficial use was considered: placement of material in existing ODMDS sites near the study area. We did not assess alternatives involving conventional disposal of dredged material within the Laguna Madre and thus did not address many issues which are discussed in the literature (see, for example, Roop and Dickerson, 1993; Diaz and Kelly, 1994).
- Practicality. It is a virtual certainty that beneficial use would be more expensive than conventional placement, and possible that it would require use of non-conventional dredging and/or placement methods. The scope of this study allowed us to consider the practicality of beneficial use only in very broad terms; there was no assessment of dredging economics or technology.
- Nature of conclusions. The development and evaluation of alternatives was not for the purpose of selecting a preferred plan of action, or otherwise predetermining the content of the Dredged Material Management Plan. All conclusions should be considered as contributing to the building of a framework or foundation for future project-specific and site-specific planning.

1.3 APPROACH OF STUDY

Beneficial use is defined as the use of dredged material "in a manner that will benefit society and the natural environment by providing services and filling needs" (Battelle, 1997, p. 9). This definition is applied in a comparative context; that is, an alternative is "beneficial" if the services provided exceed those from non-beneficial placement. There is no advance determination (one way or the other) whether such alternatives have net environmental benefits and/or are cost-effective.

As discussed above, we considered only uses that would directly benefit the Laguna Madre ecosystem. Based on professional judgments of the study team, and insights from the beneficial use literature (e.g. Battelle, 1997, and references therein), we identified three types of environmental services which dredged material may provide to satisfy the habitat needs of the Laguna Madre ecosystem: protection, nourishment and habitat creation.

- Protection. The service of protection applies to habitats which experience wave or wind erosion. The environmental need is to reduce the energy of the erosive agent, increase the resistance of the substrate, or otherwise reduce the severity of erosion. Some types of dredged material may have the potential to fulfill this need, as by using the material to build barriers (berms or levees), provide shoreline armor, or serve as a soil cover.

- Nourishment. The service of nourishment applies to habitats that experience erosion, and also to those that may be deficient in nutrients, or otherwise would benefit from having an additional supply of mineral matter. The environmental need is to obtain a supply of the material that is being lost or is deficient. Dredged material may fulfill this need by replacing eroded sediments and/or by providing nutrients and organic matter. Nourishment is one service that does not necessarily require the dredged material to stay in place.

- Habitat creation. The service of habitat creation typically involves constructing a subaerial or subaqueous landform on which a particular floral/faunal association is expected to develop. This satisfies the general ecosystem need of having diverse and productive habitats. To provide the service of habitat creation, the dredged material must provide the landform(s) and substrate characteristic of the target habitat, and then support natural vegetation and processes.

In order to develop alternatives for beneficial use of dredged material, it is necessary to investigate the habitats of the Laguna Madre, in order to determine their environmental needs; and to assess the capabilities of the dredged material in meeting these needs. Thus the approach used in this study included habitat characterizations (Section 2) and dredged material characterization (Section 3), as predicates to the development and evaluation of alternatives (Section 4).

1.4 STUDY METHODS

Information regarding the Laguna Madre was compiled primarily through a literature review; see the list of references for this report. The published literature on the Laguna Madre is extensive. The focus of the literature survey is to characterize factors most important to the evaluation of the beneficial use alternatives. In this context, information was gathered on the following environmental elements:

- past and prospective dredging activities, and fate of disposed material;
- general hydrology and ecology of Laguna Madre and environs;
- water and sediment quality, and potential pollution sources;
- substrate characteristics, including conditions at the existing ODMDS;
- ecological conditions, especially seagrass populations and colonial sea birds; and
- human uses of the Laguna Madre area.

In addition to the literature review, the authors of the report collectively or individually: 1) spent five days in the field in June, 1997, to collect water and sediment samples and visit site features; 2) undertook a ground reconnaissance and low-altitude overflight of the Laguna Madre in August, 1997; and 3) discussed (by phone or in person) environmental issues and/or dredged material issues with numerous persons knowledgeable about the Laguna Madre region, including most ICT members. The development and evaluation of alternatives involved the application of professional judgments which were informed by the literature review, field visits and insights gained from networking.

1.5 ORGANIZATION OF REPORT

The report is organized as follows.

1. Introduction. Outlines the overall approach and organization of the report.

2. Environmental overview. Provides a brief description of the highly diverse and productive ecosystem of the Laguna Madre, including the hypersaline lagoon and associated barrier island. Summarizes environmental conditions in the Laguna Madre system (such as decreased salinity, loss of seagrasses, and the occurrence in certain areas of an algal bloom known as brown tide) which provide the background and context for the evaluation of alternatives.

3. Dredged material overview. Summarizes those aspects of the past and prospective dredging and placement program of the USACE which directly affect the formulation and/or evaluation of beneficial use alternatives, including the physical characteristics of the material which is available for use, and the characteristics of the offshore sites.

4. Formulation and evaluation of alternatives. Discusses the formulation of alternatives and outlines the options that have been considered for the beneficial use of GIWW dredged material. Presents a framework for the evaluation of the alternatives. Also, provides an assessment of the suitability of GIWW dredged material for placement into the designated ODMDS.

5. Summary and recommendations. Summarizes the factors that appear most critical to any analysis of beneficial uses that will be part of the Dredged Material Management Plan, and provides our recommendations to EPA and the ICT.

Figure 1-1. General location map, Laguna Madre, Texas

FIGURE 1-2. USGS 1:250,000 LOCATION MAP

See map pocket at back of report.

TABLE 1-1. CATEGORIES OF BENEFICIAL USE OF DREDGED MATERIAL

Source: Battelle (1997), reflecting USACE (1987).

1.	Habitat Development	Using dredged material to build and restore wildlife habitat, especially wetlands or other water-based habitat (e.g., nesting/islands, offshore reefs).
2.	Beach Nourishment	Using dredged material (primarily sandy material) to restore beaches subject to erosion.
3.	Aquaculture	Using dredged material for aquaculture can be explored depending on the nature of the materials. Considerable caution should be exercised to ensure that the dredged material is free of contaminants that could bioaccumulate.
4.	Parks and Recreation	Using dredged material as the foundation for parks and recreational facilities; for example, waterside parks providing such amenities as swimming, picnicking, camping or boating.
5.	Agriculture, Forestry, and Horticulture	Using dredged material to replace eroded topsoil, raise the soil surface, or improve the physical and chemical characteristics of soils.
6.	Strip-mine Reclamation & Solid Waste Management	Using dredged material to fill and re-contour strip mines to provide daily cover or final capping of landfills, or to cap contaminated dredged material discharged at open-water sites.
7.	Shoreline Construction	Constructing such shoreline structures as levees, dikes, and confined placement facilities out of dredged material.
8.	Construction/Industrial Development	Using dredged material to support commercial or industrial activities, primarily near waterways; for example, expanding or raising the height of the land base, providing bank stabilization, and so forth. In addition, dredged material may be used as construction aggregates and material.
9.	Multiple-Purpose Activities	Using dredged material to meet a series of needs simultaneously, such as habitat development, recreation, and beach nourishment, which might all be supported by a single beneficial use project.

2. ENVIRONMENTAL OVERVIEW

Any evaluation of the beneficial use of dredged material placement in Laguna Madre must be done in the context of existing environmental conditions. Numerous studies have documented these conditions and their dynamic changes, and are briefly summarized here. The summary is intended as reference material for the existing study and (with appropriate expansions) for future studies. Readers familiar with the environment of the Laguna Madre may wish to go to Section 3 of this report.

The Laguna Madre is a 200-kilometer long estuarine lagoon that lies behind a continuous barrier, Padre Island. The lagoon and associated island are characterized by: relatively abundant coarse sediments (though those removed by maintenance dredging are relatively fine); limited freshwater inflow; an arid climate; and a limited tidal range. The Laguna Madre is one of the world's three major hypersaline lagoon systems (Gunter, 1967) and, until the middle of this century, was subject to primarily natural changes as a result of mostly wind and tide driven processes. It contains about 80% of the state's coastal seagrass meadows (Quammen and Onuf, 1993). During the last 50 years, more than 50% of the finfish catch from Texas bays has come from the Laguna Madre (Britton and Morton, 1993). Ecological changes in recent years include reduced salinity, changes in seagrass distribution, and occurrence of brown tide.

2.1 PHYSIOGRAPHY

The landscape of the Laguna Madre has three major units: the barrier island; the lagoon itself; and the mainland.

Padre Island. The barrier island complex developed as sandy sediments accreted onto and along the coastal plain during the late stages of the present postglacial rise of sea level (Wanless, 1976; Brown et al., 1977). The natural processes tended to build the barrier island both seaward and landward, and to close or limit tidal passes. Thus, with the exception of the man-made Port Mansfield Navigation Channel near its center, the barrier is continuous between the natural but federally maintained tidal passes of Aransas Pass in the north and Brazos Santiago Pass in the south.

Elevation and width vary considerably along the island. Schematic sections across the island and lagoon are shown for the northern and southern portion of the island and lagoon in Figures 2-1 and 2-2, respectively. Dune complexes account for the highest elevations of the island. On the northern third of the island, dune ridges are continuous and reach elevations in excess of 13 meters. Dune width and elevation decrease generally southward as increased aridity and decreasing vegetative cover limits retention and accumulation of windblown sands.

Vegetated barrier flats with isolated dunes occupy most of the barrier surface behind the dune ridges on the land side (Weise and White, 1980). Toward the south, dune ridges and vegetated barrier flats give way gradually to sand flats with isolated coppice dunes. Lesser elevations and limited or absent vegetative cover allow localized washover from the Gulf during storm tides and extensive transport of sediments by wind so that the backside of the barrier becomes characterized by extensive washover and tidal flats.

Although Padre Island supports a large variety of wildlife, its greatest value and function may be that, by sheltering the estuarine environment and constraining tidal exchange, the island acts as an essential control for maintaining the hypersaline characteristics of the lagoon (Shew et al. 1981).

<u>Laguna Madre</u>. The lagoon coincides with the shallow depression between the Padre Island barrier and the mainland. The development of high tidal flats (the Saltillo Flats) through accretion from the barrier toward the mainland separated the lagoon into the Upper (northern) and Lower (southern) Laguna Madre during the 19th century (Brown et al., 1977). Construction of the Gulf Intracoastal Waterway (GIWW) Land-Cut segment through the Saltillo Flats reconnected the upper and lower lagoon in 1949.

The upper and lower lagoon differs in a number of geomorphic aspects. The Upper Laguna Madre is generally narrower and shallower with depths from 0.6 to 1.5 meters (Figure 2-3). It is regionally characterized by three large depressions that are separated by shoal areas from each other and from Corpus Christi Bay. The most prominent depression occurs in the central area east and south of Baffin Bay. Because better vegetative cover in the upper lagoon along both Padre Island and the mainland decreases wind-induced transport of sand into the lagoon, mud and tidal flat development along the upper lagoon margins is less extensive than in the lower lagoon. Tidal flats occur mostly in the area south of Baffin Bay as a 2 to 3 kilometer wide transition between the barrier island and the lagoon. In the area known as the Middle Ground, the flats extending from the barrier island are more extensive. On the mainland side, mud and tidal flats become prominent south of the Middle Ground. The tidal and mudflats widen on both sides of the lagoon toward Saltillo Flats and completely surround the area known as "The Hole", the southernmost and shallowest of the large depressions in the upper lagoon.

The Lower Laguna Madre contains two major depressions, in the northern and southern one third respectively, with depths from 0.6 to 2.5 meters (Figure 2-3). A broad shoal area with depths of about 0.5 meters separates the two in the vicinity of Arroyo Colorado. Because of washover and eolian sediment transport off the barrier, lagoon margins are very shallow on the Gulf side. The lagoon margin is characterized by 3 to 4 kilometer wide tidal flats in the northern two thirds of the lower lagoon. Tidal flats are limited along the lower portion of Padre Island.

Lagoon bathymetry has been altered by construction of the GIWW. Depth of the GIWW is maintained at about 3.66 meters (12 feet), compared to the 0.6 to 0.9-meter (2 to 3 foot) average natural depth of the lagoon. The shallow depths of the lagoon necessitated major excavation and placement of dredged material. Dredged material deposits extend above the water surface in many parts of the lagoon, particularly in the shallower Upper Laguna Madre. Dredged material deposits are located on both sides of the GIWW. Most placements have been on the east side in the Upper and on the west side in the Lower Laguna Madre (refer to Figures 1-2 and 2-5).

Mainland. The area inland of Laguna Madre is part of the extensive Pleistocene barrier-strandplain and fluvial-deltaic complex that developed along the Gulf of Mexico during the previous high stand of sea level. The area was subsequently dissected as sea level fell prior to the Modern high stand (Britton and Morton, 1989; Weise and White, 1980; Brown et al., 1976, 1977, 1980). Infilling of stream valleys and development of an extensive sand/loess sheet during the most recent episode of sea level rise now obscures much of this Pleistocene coastal terrace. Along the Upper and northern Lower Laguna Madre, the mainland shores are sand dominated and generally characterized by sparsely vegetated prairies with wind-eroded depressions and isolated dune fields. The area is used primarily for grazing. Along the southern Lower Laguna Madre, finer sediments associated with old Rio Grande meander belts and deltaic deposits allow a denser vegetation cover of grasslands and woody vegetation, and extensive cultivation.

Anthropogenic modifications. Many of the human modifications in the Laguna Madre are similar to other localities in the Gulf Coast. Jetties have been built to armor and maintain both the Port Mansfield Pass at roughly the midpoint of Padre Island and the Brazos Santiago Pass at the southern end. The jetties are constructed of granite, limestone and sandstone boulders with a 50-meter width at the base and a 4-meter crest width. These passes provide a navigational and hydraulic link between the Laguna Madre and the Gulf of Mexico. Yarborough Pass, located north of Port Mansfield Pass, was repeatedly dredged as an artificial inlet between the 1940's and early 1950's to provide gulfside access for recreational fishing interests. However, the tidal prism was insufficient to maintain the unarmored channel.

Two forms of shoreline development have occurred in the Laguna Madre in response to the recreation and tourism industry. Many of the dredge material islands along the length of the GIWW have been leased by the state to individuals who have constructed cabins for fishing and other recreational purposes. In some instances, this island development also has included small walkways and boat docks. The cabins are seasonally occupied and have low population densities.

The second form of shoreline modification, urbanization, includes Corpus Christi, Port Mansfield and Port Isabel on the mainland, and South Padre Island on the barrier. Infrastructure modifications include hardening of the shoreline with the removal of South Padre dunes, construction of lagoon-side housing developments, access canals, piers, bulkheads, groins, storm drains, landfill to support private dwellings, and commercial development, such as marinas, boat maintenance, cargo docks, etc. This development has resulted in increased vessel traffic in the lagoon and pedestrian traffic on the barrier island, and has the potential to impact water quality from surface runoff, storm drains, municipal and industrial discharges into the Laguna Madre.

Oil and gas development has resulted in the dredging of several access canals and brine pits on both the mainland and backbarrier environments. However, it appears that some of the canals and pits were converted to "made" land (Brown et al., 1977). Some dredged material also has been used to construct "pads" for well sites in and near Baffin Bay.

Agricultural drainage has reduced salinity and raised nutrient inputs near the mouths of Baffin Bay and Arroyo Colorado (Cifuentes et al., 1997).

The most pronounced anthropogenic modification in the lagoon is related to dredging activities. As discussed subsequently, the subaerial and subaqueous dredged material placement areas have combined to alter the circulation patterns and habitats of the Laguna Madre.

2.2 CLIMATE AND HYDROLOGY

Climate. The climate is subtropical semiarid; annual rainfall ranges from 100 centimeters in the northern part of the planning area to 50 centimeters in the south. The strongly evaporative water balance allows hypersaline conditions to be maintained in the lagoon as long as there is limited introduction of less saline ground or surface water and limited exchange with the Gulf of Mexico.

Wind conditions are an important factor controlling water level variation and sediment transport (Brown et al., 1997; Militello et al., 1997). The area is characterized by two seasonally dominant wind regimes. Persistent southeasterly winds dominate from March through November and blow diagonally across the barrier/lagoon system from the Gulf at speeds that are mostly between 6 and 12 meters/second (14 and 27 mph). During the winter, southeasterly winds alternate with one to three days of northerly winds when cold fronts move through the area, about 15 to 20 times each year (Hayes, 1965). The northerly winds are usually stronger with average speeds of 12 to 17 meters/second (27 to 38 mph), and blow generally along the lagoon axis.

Hydrology. Hydrologic conditions in the Laguna Madre are influenced primarily by climatic conditions, and to a lesser extent by freshwater inflow and tidal exchange. Much of the water level variation in the Laguna Madre is wind-driven and therefore follows a seasonal pattern responding to changes in predominant wind direction and wind velocities. The predominance of southeasterly winds during the spring and summer induce northerly currents in the lagoon. This drives a circulation pattern which brings water in from the Gulf through the Brazos Santiago Pass, moves water from the Lower to the Upper

Laguna Madre, and then out through the causeway outlets to Corpus Christi Bay and through Aransas Pass to the Gulf (Brown et al., 1976, 1980; Quammen and Onuf, 1993).

Breuer (1962) indicated that circulation is greater in the Lower than in the Upper Laguna Madre. A contributing factor is the presence of an additional opening in the lower lagoon north of Brazos Santiago Pass -- Port Mansfield Channel. In addition to contributing to an introduction of water through Brazos Santiago Pass, northward water movement is believed to increase water levels in the northern end of the Lower Laguna Madre, causing accelerated water movement through the GIWW into the Upper Laguna Madre.

In shallow water systems such as Laguna Madre, wind-generated waves appear to be the dominant mechanism for resuspension of sediment (Ward, et al. 1984; Onuf, 1994; Schoelhammer, 1995). Transport of suspended sediments, and thus distribution of associated turbidity, is then affected by both wind and tidally induced water currents. Eolian transport over dry surfaces is another significant component of the movement of sediments in the Laguna Madre system.

Cross-channel flow in the Laguna Madre is important because of its contribution to the process of wash back of sediments into the GIWW channel. In the Lower Laguna Madre, there is a northeast-southwest cross-channel flow that is largely wind-induced, but also follows the configuration of the naturally deep area of the lower lagoon (Brown et al., 1997). This cross-channel current carries turbid water across the GIWW, where it can be re-deposited, and coincides with the characteristically high-shoaling reach (Brown et al., 1997).

There is also a distinct cross-channel current in the northern end of the Upper Laguna Madre (southern Corpus Christi Bay) (Militello et al., 1997). A clockwise gyre set up by persistent southeast winds carries sediment across the GIWW, again in a characteristically high-shoaling reach.

Freshwater inflow occurs as local runoff from adjacent coastal watersheds after major precipitation events, and as wastewater returns from irrigated areas and municipalities. No major streams enter the Laguna Madre, although there is an indirect influence of the Rio Grande via Brazos Santiago Pass, and there is substantial routing of floodwaters, irrigation return flows and wastewaters into the Lower Laguna Madre through the Rio Grande North Floodway and the Arroyo Colorado. Most of the fresh water entering the Upper Laguna Madre does so through Baffin Bay. Overall, freshwater introduction is limited and highly variable. TNRCC (1996) summarized the water budget for the Upper Laguna Madre, on an annual basis, as

Inflow	194	million cubic meters
Precipitation	+490	
Evaporation	-1,040	
Water balance	-289	million cubic meters.

In the Lower Laguna Madre, inflow is greater but evaporation also is greater.

Tidal water exchange with the Gulf of Mexico is limited because of the small range and mainly diurnal nature of the tide, the continuity and elevation of the Padre Island barrier, and the presence of bathymetric constraints on water movement at the northern and southern end of the Laguna Madre. The astronomical tidal range along the Gulf coast of Padre Island is about 0.5 meters. Attenuation of the tidal amplitude through the tidal passes, shallow water depths, and extensive seagrass beds collectively reduce the astronomical tidal range to less than 15 centimeters at the entrances to the Upper and Lower Laguna Madre, and to nearly zero north and south of the Land Cut, despite the Port Mansfield Channel connection with the Gulf. Smith (1978) noted that tides in the Upper Laguna Madre accounted for only 5% of the total observed water level variation, whereas cold front passage may result in a water level change of 30 to 45 centimeters.

The northward movement of water contributes to the estuarine system in a number of ways. For example, it is important as a constraint on southward diffusion from the Upper Laguna Madre during the warmer months, when light-reducing brown tide is most developed and algal concentrations are higher in the Upper than in the Lower Laguna Madre. The increased introduction of less saline water through Brazos Santiago Pass during the warmer months is important also as a mechanism to regulate water salinity and temperature within the lagoon.

The freshwater deficit and limited tidal water exchange, combined, have allowed Laguna Madre to be naturally maintained as a hypersaline system, i.e., salinities ordinarily exceed those of sea water. Salinities in the Lower Laguna Madre are generally somewhat lower than those in the Upper Laguna Madre by about 4-6 parts per thousand (ppt) (Sheridan, 1996). This is, in part, because of the more direct connection with the Gulf through the Brazos Santiago Pass where discharge of the Rio Grande causes freshening of the adjacent Gulf waters; and also because of the greater freshwater flux in the lower lagoon. However, salinities have decreased since the middle of this century, probably as a result of several anthropogenic causes including construction of the GIWW (Quammen and Onuf, 1993). Salinity records for the period of 1962 through 1974 showed a decline of average monthly salinity from about 40 ppt to 35 ppt with a range of 55 ppt to 15 ppt and an annual variation of typically 15 to 20 ppt (Shew et al., 1981). Accordingly, salinity gradients may reverse as salinities increase above and fall below those of the Gulf of Mexico.

<u>Water quality</u>. For purposes of water quality monitoring and assessment by the State of Texas, the Laguna Madre is stream segment 2491 (TWC, 1990; TNRCC, 1994). This segment does <u>not</u> include, from north to south, the adjacent water bodies of Corpus Christi Bay, Baffin Bay, the Arroyo Colorado, or South Bay (refer to Figure 1-1). Nor does it include the Brownsville Ship Channel, which divides the Laguna Madre from South Bay (Figure 1-2).

Under contract to the Corps of Engineers, Espey, Huston and Associates (EHA, 1996) reviewed and summarized existing water and sediment quality data and tissue chemistry findings for the Laguna Madre. The study analyzed data from monitoring stations maintained by the following agencies:

- Texas Natural Resource Conservation Commission (TNRCC)
- U.S. Army Corps of Engineers (USACE)
- Texas Water Development Board (TWDB)
- U.S. Fish and Wildlife Service (USFWS)
- National Oceanic and Atmospheric Administration (NOAA)
- U.S. Environmental Protection Agency (USEPA).

Results of the study, by water quality segment and medium (water, sediment, tissue) are summarized in Table 2-1. For a slightly historical perspective, the table also includes findings from the 1990 Texas Water Quality Inventory.

The Espey, Huston and Associates study (EHA, 1996) has the following conclusions.

- Potential trends noted were "the higher concentrations of sediment metals at select stations within the upper Laguna Madre and Baffin Bay complex, the decreasing concentrations of sediment metals and TSS [total suspended solids] with distance along the Arroyo Colorado, and larger ranges of values around the Port Mansfield Channel and Port Isabel." (p. 18)

- "[W]hile the USACE sediment data may or may not indicate a temporal increase in sediment metals for the upper Laguna Madre, they apparently do not indicate Baffin Bay as a source of trace metals associated with oil and gas activity." (p. 18)

- "While Davis et al. (1995) state 'no station exhibited a high potential for toxic chemical impact', stations 7 and 8 (Arroyo Colorado and North Floodway mouths, respectively) were in the top three most contaminated stations for that study and were considered to have 'slight potential for toxic chemical impact'." (p. 19)

- "While the data examined for this report found few trends, those noted immediately above would indicate potential, if not actual, sources of contamination." (p. 19)

As indicated above, and in Table 2-1, most concerns focus on the Arroyo Colorado. The Arroyo Colorado is the major surface water drainage in the Lower Rio Grande Valley, and is sustained by irrigation returns and municipal wastewater. Because the flow is effluent-dominated in segment 2202 *above* tidal influences, nutrients and fecal coliform bacteria are frequently elevated (TWC, 1990). Major contributors of nutrients are municipal effluents, urban stormwater and shrimp farm effluent. Agricultural pesticide residues have been a recurring problem also (TWC, 1990). TWC (1990) lists the Arroyo Colorado *below* tidal influences (the relatively unpopulated segment 2201) as the third most severe estuary in Texas exhibiting hypoxia associated with algal blooms.

TNRCC (1994) reported elevated levels of phosphorus and ammonia-nitrogen in the Arroyo Colorado tidal segment. Wide fluctuations in dissolved oxygen concentrations occurred from 1990 to 1993 due to intense algal metabolism. Over 40% of the 267 dissolved oxygen values measured over the ten-year period did not meet the screening levels of 4.0 milligrams/liter (mg/l). For the Laguna Madre, TNRCC (1994) screened existing data and identified ammonia-nitrogen as a "possible concern"; approximately 11% of 277 ammonia-nitrogen values exceeded the screening level of 0.15 mg/l. In addition, TNRCC (1994) reported about 16% of the Laguna Madre as restricted for oyster harvesting due to fecal coliform contamination.

Section 3.4.1 of this report summarizes water quality information obtained from characterization of dredged material done in association with this project.

2.3 HABITATS

Because this report is intended to provide a generic overview of beneficial use alternatives, the geographic context of the evaluation is in the form of habitat types, which in effect are environmental planning units. Each habitat type represents an assemblage of landscape or seascape features which has a certain physical form and hydrologic regime, such that there is a reasonably predictable pattern of biological habitats and processes.

Environmental planning units were grouped as barrier island, lagoon margin, seagrass beds, unvegetated lagoon mud, dredged materials, and mainland. Figure 2-4 illustrates the typical distribution of each of the major habitat types considered. Table 2-2 summarizes key features of these habitat types. Primary references for more detailed characterizations are Britton and Morton, 1989; Weise and White, 1980; Brown et al., 1976, 1977, 1980; Shew et al., 1981; White et al., 1983, 1986, 1989.

2.3.1 Barrier island habitats

The primary emergent barrier environment, from the Gulf toward the lagoon, is a dune complex consisting of barrier island beaches, dunes and flats.

Barrier beaches. Gulfside beaches are wide deposits of fine sand and shell linked to a backbeach that forms a transport surface leading to foredune, coppice dune, and washover flat environments. The shell deposits are locally concentrated and increase in frequency to the south. Cross-shore transport from storm winds and waves provides a major link to the backbarrier and lagoon environments of Padre Island. Longshore transport direction is variable, but pronounced northward transport is evident at the Mansfield Cut and Brazos Santiago Pass jetties throughout the year. The beaches farther to the north undergo a reversal in net transport direction with northward transport during the summer and net southward transport characterizing the entire year.

Beach erosion along Padre Island is about 1.5 meters per year in the Upper Laguna Madre and 0.9 to 3.7 meters per year in the Lower Laguna Madre. A locally accelerated rate of 6.4 meters per year occurs on the downdrift side of Mansfield Pass jetties (Brown et al. 1976). South Padre Island is more susceptible to rapid erosion because of a sand deficit, high longshore drift rates, and an inherently thin barrier island sand body.

Barrier dunes. On Upper Padre Island, coppice dunes separate the beach from a ridge of fore-island dunes (Figure 2-1). Fore-island dunes, and stabilized blowout dunes immediately behind them, occupy about one third of Upper Padre Island in a one kilometer wide band along the Gulf. The fore-island dunes are mostly grass covered and range in height from about 6 to 12 meters. Generally, the ridge is about 60 to 100 meters wide. Continuity and height decrease in a southerly direction as washover channels from the Saltillo Flats southward increasingly interrupt the dune complex. Sea oats and morning glory comprise the dominant vegetation cover in the fore-island dunes, with seacoast bluestem in the stabilized secondary dunes.

The fore-island dune ridge terminates halfway between Saltillo Flats and the Mansfield channel with diminution of vegetation required to stabilize accumulated sand. From here on southward, coppice-dune fields, that only separate the foredune ridge from the beach on Upper Padre Island, dominate the entire seaward side of the island. They extend inland for a distance of about one kilometer where they merge with the high wind-tidal flats of the lagoon margin and back-island dune fields. The coppice dunes are highly unstable and height generally does not exceed 1.5 meters. They provide only temporary storage of sands being moved from the beach onto wind-tidal flats and into the lagoon by storm surges and wind.

Barrier flats and back-island dunes. Along all of Padre Island, a platform slopes gently from the gulfside dunes toward the lagoon over a distance of about 3.2 kilometers. Much of this platform is characterized by back-island sand dune fields that reach their highest concentration on the lagoon side. The central portion of the platform comprises vegetated and unvegetated barrier-flat environments. The back-island dune fields are highly mobile and change continuously in areal extent and location (Brown et al. 1977). Sands are largely supplied on Upper Padre Island by blowout dunes that migrate across the island, and on Lower Padre Island by sand reworked from washover deposits (Weise and White, 1980). Dunes are generally less than 3 meters high.

The barrier flat environment that separates the fore-island and back-island dune environments is vegetated on Upper Padre Island. Because of greater stability, depressions within these vegetated flats may remain for some time as ephemeral fresh and brackish marshes. On Lower Padre Island, the barrier flat is unvegetated and may be submerged during extreme tides; it is primarily a deflation feature from which sands and finer sediments are removed by wind down to the water table. Sediments are generally less sandy than those of the Upper Padre Island barrier flats because of deposition of fine grained sediments during limited submergence. These unvegetated barrier flats are a transitional environment to the high wind-tidal flats of the lagoon margin; thin algal mats may form locally in the lower areas.

2.3.2 Lagoon margin habitats

Wind-tidal flats. Tidal flats occupy in excess of 50% of the Lagoon environment. Most of the tidal flats occur on the barrier side of the lagoon as a result of past or continuing washover, but they have developed also through deflation and where stream discharges enter the lagoon, such as near the mouth of the Arroyo Colorado. With that exception, tidal flats are generally limited in extent and scattered along the mainland side of the lagoon. Topographic and sediment features of the tidal flats are largely governed by winds (Withers, in Tunnell et al., ed., 1996). Not only does wind-transported sand contribute to expansion of the flats, submergence is a function of wind driven water level variation that governs algal growth and carries suspended, fine-grained sediments onto the sandy flats.

Tidal flats are most extensive in the Land Cut area (Saltillo Flats), probably related to previous existence of a major breach, and in the area south of the Land Cut where discontinuity and low elevations of the dunes allow more frequent washover. Conversely, high foredunes and vegetative cover have limited tidal flat development along Upper Padre Island. Tidal flat development is also limited along the southernmost portion of Lower Padre Island, related perhaps to greater initial water depth and barrier evolution.

Only a small portion of the flats is affected by astronomical tides. Most of the tidal flats are subject to flooding only when water levels are elevated as a result of wind, hence the term wind-tidal flats. Flooding occurs mostly during periods of persistent southeasterly winds, or during strong northers associated with cold front passage. Tidal flat elevations range from mean sea level to one meter above sea level. In general, the flats slope imperceptibly from the shore toward the lagoon, resulting in a differentiation within the tidal flat environment that relates to frequency and depth of flooding. The same differentiation may result where elevation changes occur as a result of deflation or where accretionary lagoon margins allow ponding of water in the area behind them.

Subtle differences in elevation within the tidal flats are reflected in sediment characteristics, salinity, biological assemblages, and dominant sediment transport mechanisms. Blue-green algal mats are a major feature on the lower and wetter tidal flats. Tidal flats range generally from high, sandy to low, muddy flats. Most flats, however, are composed of both sand and mud with interbedded algal laminae. Algal growth occurs on the flats for extended periods as a result of submergence or ponding of rainwater where the water table is close to the surface. Maximum algal growth occurs from early May to late June, and minimum growth in October and November (Shew et al. 1981).

The high tidal flats are only submerged about 5% of the time (Herber, 1981), and the surface is normally dry. As a result, wind transport is the dominant sediment transport mechanism and small dunes form on its surface. Algal growth may be present in deflation depressions where sediment is moist and water is ponded during rainfall or the occasional flooding as a result of finer sediments and decreased permeability. Rooted vegetation may occur in isolated occurrences. The primary example of this type of environment is the Saltillo Flats at the Land Cut, but high tidal flats typically form the transition between the barrier sand flats and the algal flats along Lower Padre Island.

As flat elevations decrease, algal mats become more extensive and, together with moisture content of the sediments, increasingly prevent deflation. Wind transport of sand onto and across these surfaces does occur from locally derived sand and from the higher flats, particularly along the Lower Laguna Madre. These lower tidal flats are most extensive along the back barrier of the northern half of the Upper Laguna Madre, on both sides of the Land Cut area, and in the Arroyo Colorado delta area. In each of these areas the flats extend inland from the lagoon for a distance of up to 4 kilometers. Extensive algal mats are present throughout the central part of the flats along southern Padre Island. Along the barrier side of the Upper Laguna Madre, generally south of Baffin Bay, they are only about one kilometer wide. Environmental mapping (by Weise and White, 1980) indicates that, in contrast to the general lagoon-ward slope of the wide flats of the lower lagoon, flats in the upper lagoon appear to have a higher elevation along the lagoon margin. This suggests a greater influence of tidal flooding, as compared to wind and washover, on sediment transport on the tidal flats of the upper lagoon.

Tidal flat productivity has been found to be comparable to that of seagrass beds (Withers, in Tunnell et al., 1996). Benthic invertebrate infauna and epifauna make tidal flats an important foraging habitat for shorebirds, Peregrine falcon, sandhill crane and other non-shorebird species (Withers, 1994). Shorebirds have been found to be most abundant from January through March, with sandpipers being observed most frequently. Little information is available on the use of wind-tidal flats by wading birds. The Tricolor Heron is often found abundant on Upper Laguna Madre flats (Withers, in Tunnell et al. ed. 1996) but other abundant species include egrets and spoonbills. The importance of wind-tidal flats of the Laguna Madre to nekton appears not to be well documented.

Lagoon-margin sands. The transition from the tidal flats to the deeper water of the lagoon is, in many areas, formed by sediments from which fine materials have been winnowed by wave action. This transition is commonly referred to as lagoon-margin sands and occurs extensively along the tidal flats of both Upper and Lower Padre Island. Padre Island and relict Pleistocene fluvial deposits are thought to be the primary sand sources (Brown et al., 1980). Lagoon-margin sands occur locally as a narrow fringe along the mainland shore of the lagoon in some areas. These sandy environments are generally shallow, with depths less than one meter. In contrast to the adjoining algal flats and seagrass beds, these areas are not vegetated. Where wave action is limited, but shallow water or wave induced turbidity limit establishment of seagrasses, the subaqueous margin is generally characterized by muddy sands.

Accretionary margins. While much of the transition from barrier/mainland environments to the subaqueous environments of the lagoon is dominated by wind tidal flats, major segments of the lagoon shore exhibit accretionary margins where wave action and sediment characteristics allow construction of a berm or narrow beach. This is the case primarily along the western shore of the Upper Laguna Madre where extensive tidal flats are absent and shoreline changes are mostly erosional. Berms may be as much as one meter above sea level (Brown et al., 1977).

Berm and beach development may also occur along the margins of major shoals within the lagoon. The most prominent examples of this process are North and South Bird Island in the Upper Laguna Madre. There, sediment accumulation was sufficiently large to develop a series of natural berms and spit-like features. Acccretionary ridges are vegetated and provide nesting habitat for a number of bird species (Weise and White, 1980).

Serpulid reefs. A more limited but unique subaqueous environment is formed by relict serpulid reefs. Serpulids are polychaetes (segmented marine worms) that build calcareous tubes that are attached to each other or to another hard substrate. When extensive enough, a conglomeration of serpulid tubes can form a reef. Such reefs occur across the mouth of Baffin Bay, and for a distance of 10 kilometers south of Baffin Bay along the mainland shore. It has been suggested that the reefs developed prior to the lagoon becoming hypersaline with increasing continuity of the Padre Island barrier (Andrews, 1964). They are currently believed to be dormant, as no living serpulids have been observed (Brown et al. 1977).

2.3.3 Seagrass habitats

Figure 2-5 shows the distribution of grass beds within the Laguna Madre. Grass beds cover approximately 730 square kilometers, or almost three quarters of the Laguna Madre, accounting for 80% of all seagrass along the Texas coast (Brown et al., 1997). The high abundance and wide distribution of seagrasses in Laguna Madre demonstrates an historically favorable habitat characterized by shallow depths and high water clarity, largely a result of the low inputs of suspended sediments through runoff (Quammen and Onuf, 1993). The predominant but declining species is shoal grass (*Halodule wrightii*), which tolerates a wide range of salinities (3 to 70 parts per thousand - ppt) and has an optimum salinity of 44 ppt (McMahan, 1968). Shoal grass dominates in the Upper Laguna Madre; in the Lower Laguna Madre, dominant species (in descending order based on biomass) are: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiformi*), shoal grass (*Halodule wrightii*), clover grass (*Halophila engelmannii*), and widgeon grass (*Ruppia maritima*) (Onuf, 1996; Brown et al., 1997). These species are somewhat less salt tolerant than shoal grass.

The distribution and species composition of seagrasses in the lagoon has been variable over time because of their sensitivity to changes in water quality, especially salinity and light penetration. Distribution and species composition are therefore influenced by a large number of processes, both natural and human induced. Major factors include quantity and quality of local runoff, circulation and tidal exchange, water depth, frequency of sediment resuspension, and algal blooms. Trends and changes in seagrass coverage and species composition related to several of these factors are discussed in Section 2.4.4.

The spatial distribution of seagrass beds generally follows water depths in the lagoon because of decreasing light availability at greater depths. In many areas, seagrasses are sparse or absent when water depths exceed 1.4 meters (Onuf, 1996). The absence of seagrasses is most notable in the two large depressions of the Lower Laguna Madre (near the southern end and northern end respectively), and in the depressions of the Upper Laguna Madre north of and adjacent to the Middle Ground and at the mouth of Baffin Bay (Quammen and Onuf, 1993; Onuf, 1996). In addition to greater depths, factors contributing to the absence of vegetative cover in these areas may be increased turbidity associated with wind- and depth-driven circulation patterns, and increased salinities in the deeper areas as a result of stratification.

While seagrass coverage is generally more extensive in the Upper than the Lower Laguna Madre, seagrass density diminishes south of Baffin Bay. Brown et al. (1977) reported seagrass meadows to be poorly developed in that area, despite local occurrences in the Hole and near the Middle Ground.

Detailed mapping of seagrass distribution and species composition by Brown and Kraus (1997) in the lower half of the Lower Laguna Madre revealed a distinct pattern. Turtle grass, interspersed with manatee grass, was found to be most abundant and occurred primarily between the unvegetated, deeper portion of the lagoon and the Padre Island lagoon-margin to the east. Turtle grass was flanked by a narrow margin of shoal grass along each of these two environments. From the deeper area westward toward the mainland a spatial succession was found from shoal grass to manatee grass. An abundance of turtle grass was similarly found by Chin (in Brown et al., 1980) near the Arroyo Colorado, and had occurred at the expense of shoal grass and widgeon grass.

Grass beds represent a highly complex environment with a very high biological productivity. The grass beds fulfill multiple habitat functions for an extensive array of faunal species, and grasses serve as substrate for epifauna and epiphytes. Major habitat functions include spawning grounds or nurseries for many fish and crustaceans such as shrimp and crabs. The most important sport and commercial fish species that utilize the lagoon are black drum, red drum and spotted seatrout. While the number of fish and shellfish species in the estuarine community of the Laguna Madre is low compared to other estuaries, populations are usually very large. Most of the fish biomass is concentrated in forage species (Shew et al., 1981).

In addition to serving as an indirect food source for fish and shellfish, seagrasses also serve as a primary food source for some animals, including migratory waterfowl (White et al. 1986). Seventy five percent of the North American population of redhead ducks (*Aythya americana*) is estimated to winter in the Laguna Madre (Shew et al. 1981). This species utilizes shoal grass as its almost exclusive winter staple, and so is dependent on this seagrass for winter survival (McMahon, 1970, in Adair et al., 1994).

2.3.4 Unvegetated lagoon mud habitats

<u>Lagoon center mud</u>. This environment occupies broad areas of the Laguna Madre basin (refer to Figure 2-5), primarily south of the Land Cut toward Port Isabel, the southern portion of The Hole, and north of Middle Ground and Baffin Bay, for a total coverage of approximately 259 square kilometers (100 square miles). Approximately 55% of the lagoon center muds are distributed south of the Land Cut, with the remaining deposits decreasing in size toward Corpus Christi. The composition of the material ranges from muddy sand to 100 percent dark gray mud. The sand admixture occurs along the flanks where the lagoon center mud interbeds with the topographically higher lagoon margin sands.

The mud is typically found at depths of 1.8 - 2.7 meters in Laguna Madre and 1.2 - 2.7 meters in Baffin Bay. Locally generated waves contribute to mixing in the shallower depths of the mud; gulf-generated swells and strong bottom currents are uncommon. The passage of storms, cold fronts and hurricanes and the resulting storm surge can elevate water level and generate waves sufficient to resuspend lagoon margin and shallow lagoon center sediments. Hence, lagoon center muds result from wind deposition and from redeposition of suspended sediments, coming largely from reworking of shallow-water substrate (natural and dredged material) and subaerial dredged material. The lagoon center mud also receives organic deposits from runoff (inland or mainland sources) and locally generated wave-induced currents (reworking of the bay shoreline). The resulting substrate diagnostic of lagoon center mud is laminated mud and mud/sand, mottled bay mud, and lagoon mud with occasional shell. The sand content increases to the south, toward the open bay near South Padre Island and Port Isabel.

Lagoon mud center bottoms support communities of benthic invertebrates, composed predominantly of polychaetes and oligochaetes (segmented worms), amphipods and other crustaceans, and mollusks (Espey, Huston & Associates, 1997). Dominant species include the polychaetes *Prionospio heterobranchia* and *Melinna maculata*, and the amphipod *Ampelisca abdita*. Fish and decopods that occupy this habitat include the bay anchovy (*Anchoa mitchelli*), the gulf menhaden (*Brevoortia patronus*), the blue crab (*Callinectes sapidus*), and a group of recreationally or commercially important species, including spot (*Leiostomus xanthurus*), croaker (*Micropogonius undulatus*), striped mullet (*Mugil *cephalus*), southern flounder (*Paralichthys lethostigma*), and gulf flounder (*P. albigutta*) (Sheridan, 1996).

The deeper areas of the lagoon complex have been reported to lack benthic organisms because of low oxygen availability, particularly the deepest parts of Baffin Bay (Brown et al., 1977). However, this is not likely to be a widespread phenomenon in the lagoon proper due to the shallow depths and low nutrient inputs, except perhaps near the mouths of Baffin Bay and Arroyo Colorado, where nutrient inputs are higher (Cifuentes et al., 1997).

2.3.5 Dredged material habitats

Dredging is the primary source of anthropogenic habitat modification in the Laguna Madre. For the last 45 years, dredging in the Laguna Madre has recurred every 12 to 36 months because of sediment resuspension, transport and deposition (wash back) into the GIWW. The dredged material volume redistributed from the lagoon depths to shallower waters is reported to exceed the sediment supply by natural erosion into the basin (White et al., 1986).

Dredged material in Laguna Madre has been placed in both subaerial and subaqueous environments as unconfined and confined deposits along the entire length of the Laguna Madre. The total area of dredged material is approximately 160 square kilometers, with unconfined subaerial and subaqueous materials the most common according to GIS data from the State of Texas (Texas, 1997) (refer to Figure 2-5).

The GIWW has changed the almost uniformly shallow, largely grassed habitat of the Laguna Madre to one that includes a long narrow feature of deeper water. The deepwater habitat is valuable to flounder and some other fish, and a transitional (seagrass bed or unvegetated bottom to deeper water) edge habitat that is valuable to redfish and speckled seatrout, among others.

<u>Seagrass beds</u>. In 1994, unconfined subaqueous placement for habitat modification was attempted in the Lower Laguna Madre (Brown et al., 1997) with the intent of decreasing water depth and thus increasing suitability of the area for seagrasses. However, monitoring of this attempt has indicated that high erosion rates of the unconfined subaqueous material, with loss of approximately 70% of open bay dredged material within approximately eight months, yielded a bottom topography similar to pre-dredging conditions (Brown et al., 1997). Very little information is available on any results of creation of shallow subaqueous habitat with coarser-grained materials available in earlier dredging cycles.

<u>Islands or mounds</u>. Subaerial deposits of dredged material in the form of islands or mounds have historically been the most common forms of placement. As of the mid-1970s, approximately 80% by area of dredged material in the Laguna Madre was in subaerial placement in unconfined and confined deposits

(Brown, et al., 1976, 1977, 1980; Weise and White 1980). The mounds or small islands occur on both sides of the GIWW in the Upper Laguna Madre between Corpus Christi Bay and Baffin Bay (Figure 1-2). Between Baffin Bay and south of the Land Cut, the dredged material occupies the east side of the GIWW and forms a broad base or platform on which additional dredged material has been stored as confined deposits behind sidecast or dragline dredged material levees.

Some of the dredged material islands in both the upper and the lower lagoon have been leased by the state and developed for recreation, primarily with fishing cabins. Many of the islands have been used by various species of colonial water birds as nesting and foraging habitat. Habitat quality varies substantially between islands, as evidenced by the brief descriptions of those islands by Coste and Skoruppa (1989). Some islands have predominantly sand substrate, notably several adjacent to the Port Mansfield Channel where sandy sediments are still available, and support large, stable numbers of nesting colonial water birds (Coste and Skoruppa, 1989). Many others are predominantly muddy substrates, and a few are characterized as hard clay.

The nature of the substrate and the presence or absence of vegetation greatly affects the species of birds that use each island, as well as nesting success. The presence and type of vegetation is not only affected by substrate type, but also by island height, age of the island, and aridity. Other factors affecting habitat quality include island size, accessibility to mammalian predators, presence of competitors, and human use and disturbance (Coste and Skoruppa, 1989).

A few islands are more exposed to wind and wave action, and have been substantially eroded or entirely lost. Of these, those that are proximal to sources of sandy material, and/or those that were highly successful nesting habitats, have been recommended for nourishment or re-building (Coste and Skoruppa, 1989).

2.3.6 Mainland habitats

Environments along the west shore of the Laguna Madre are predominantly of three types: lagoon margin sands and wind tidal flats; sand-loess prairies and saltmarsh; prairie grass lands and fluvial woodlands. Lagoon margin sands and wind tidal flats were discussed previously in Section 2.3.2.

Sand-loess prairie; saltmarsh. Mainland shores along the upper and northern half of the Lower Laguna Madre are composed predominantly of loose sand and loess prairies with deflation depressions that hold freshwater marsh during wet cycles. The prairies are impacted by grazing and are sparsely vegetated, primarily with bunch grass. The absence of extensive tidal flats along the shore of the Upper Laguna Madre has allowed berm and swale development by wave action along much of the shore north of Baffin

Bay. The swales support saltmarsh vegetation. In general, the area encompassed by emergent, vegetated wetlands is small and mainly confined to the southern portion of the Lower Laguna Madre.

Prairie grasslands; fluvial woodlands. Prairie grasslands and fluvial woodlands dominate the mainland along the southern half of the Lower Laguna Madre. The Laguna Atascosa National Wildlife Refuge contains extensive tidal flats and fluvial and deltaic environments. Continuity of the shore environments is somewhat broken by the remnants of the Arroyo Colorado delta. Although mostly subsided and transgressed by tidal flats, emergent natural levees serve as nuclei for active clay-sand dunes (Brown et al., 1980). Delta development was terminated with construction of the Arroyo Colorado Cutoff channel.

2.4 CHANGES IN ENVIRONMENTAL CONDITIONS

2.4.1 Reduced salinity

Changes in salinity have the potential to profoundly affect the ecology of the Laguna Madre, including the diversity, distribution and abundance of seagrasses and associated fauna.

Both the average and range of salinities in the Laguna Madre are lower now than they were in the mid-1940s. Monthly data from 1946-48 showed a salinity range of about 45 parts per thousand (ppt) to 115 ppt in the Upper Laguna Madre, and about 35 ppt to 70 ppt in the Lower Laguna Madre (Quammen and Onuf, 1993). In the Upper Laguna Madre, salinity exceeded 60 ppt in 33% of the observations made in 1946-48, and in the Lower Laguna Madre, salinity exceeded 50 ppt in 38% of the observations. In comparison, salinity has remained below 60 ppt in the upper lagoon since the early 1950s, and mostly below 50 ppt since about 1967 (Quammen and Onuf, 1993). In the lower lagoon, salinity has remained below 60 ppt since the early 1950s, and has rarely exceeded 40 ppt since about 1967.

Several factors are thought to contribute to this change in lagoon salinities. Dredging of the Gulf Intercoastal Waterway (GIWW) through the lagoon, completed in 1949, reconnected the upper and lower lagoon through the Land Cut (Saltillo Flats), and increased water exchange with the Gulf of Mexico. Prevailing southeasterly winds drive a northward circulation pattern of Gulf water in at Brazos Santiago Pass, north through the Lower Laguna Madre and into the Upper Laguna Madre, and out through Corpus Christi Bay and Aransas Pass. Water brought in through Brazos Santiago Pass is fresher than open Gulf water due to the influence of the Rio Grande. Also, the Port Mansfield Pass, cutting across Padre Island, was made permanent in 1962, and contributes to increased water exchange in the Lower Laguna Madre. Exchange of water in the upper lagoon is limited at its northern end to the JFK Causeway. If the causeway were raised or otherwise opened, the same volume of water would be exchanged, but the currents through the GIWW would decrease, and the exchange would occur over a broader area.

Flows in the North Floodway and Arroyo Colorado, the two main drains for the lower Rio Grande agricultural district, have increased progressively since the mid-1900s (Quammen and Onuf, 1993). Temporal changes in the combined drainage flows are notable: flows exceeded 0.28 cubic meters per second (10 cubic feet per second) eight percent of the time from 1941-52; 35% of the time from 1966-78; and 72% of the time in 1976-86 (Quammen and Onuf, 1993). The main sources of the increase are attributed to a substantial increase in tilled acreage replacing perennial brush and grassland, and a substantial increase in the installation of subsurface drainage pipes in irrigated fields to counteract buildup of salinity in the root zone. Urban stormwater is also a component of the flows.

A doubling of wastewater discharge into the drain system between 1965 and 1987 contributed only about 0.28 cubic meters per second (1 cubic foot per second) to total drainage flows. Drain flows may be especially important in moderating salinity, because the greatest irrigation and associated drain flow occurs when dry, hot climatic conditions put the greatest stress on crops. This is also the time when the same climatic conditions tend to maximize hypersalinity.

2.4.2 Changes in barrier island integrity

While Upper Padre Island is in an equilibrium phase of barrier island development, Lower Padre Island is in an erosional phase (Weise and White, 1980). Lower Padre Island is becoming narrower, with more breaks in the dunes, more overwash areas, and greater frequency of breaching south of Port Mansfield Pass.

The Padre Island barrier has been breached and overwashed by numerous major hurricanes that have struck the Gulf coast, including Carla (1961), Beulah (1967), Celia (1970), and Allen (1980) (Militello et al., 1997). North Padre Island was breached at Corpus Christi Pass in 1961 and 1967, and formed a flood tidal delta as it closed in 1967. Packery Channel and Newport Pass are also active hurricane washover areas. In 1967, Hurricane Beulah, a category 5 hurricane, caused from 31 to as many as 67 breaches and storm passes over the length of Padre Island (Brown et al., 1997).

As a result of the breaches and washovers, hurricanes bring a substantial load of sediment into the Laguna Madre. Washover fan deposits associated with hurricanes are one of the most important sources of sediment in the lagoon (Britton and Morton, 1989).

2.4.3 Occurrence of brown tide

Brown tide consists of a dense bloom of a new species of chrysophyte, tentatively named *Aueroumbra lagunensis* (Militello et al., 1997). Brown tide has occurred persistently in the Upper Laguna Madre since June 1990 (Onuf, 1996). It apparently originated in Baffin Bay and flourished in conditions made favorable by a regional drought that increased hypersalinity, and a freeze-induced fish kill that provided organic and inorganic compounds that might otherwise have been limiting (Stockwell et al, 1993, in Onuf, 1996). It was probably transported by the wind-generated currents that predominate in the lagoon (Militello et al., 1997). Continued persistence of the brown tide in Upper Laguna Madre is attributed to limited water exchange, lack of natural predators, and perhaps also to availability of ammonia regenerated from dying seagrasses (Onuf, 1996). Brown tide is occasionally transported to the Lower Laguna Madre from the upper reach, but does not persist there.

One significant impact of the brown tide in Upper Laguna Madre is a substantial reduction in light penetration. There has been on the average a 50% to 60% reduction in light reaching the seagrass canopy (Onuf, 1996; Dunton, 1994). The density of the brown tide, measured by chlorophyll concentration, accounts for 65% of the variation in light attenuation values in the upper lagoon (Militello et al., 1997). In contrast, total suspended solids accounts for more than 80% of the variation in light attenuation in the lower lagoon (Brown et al., 1997).

Light attenuation showed a gradient from north to south in the upper lagoon in 1991 and 1992, corresponding to an increasing density of brown tide from north to south. This gradient broke down in 1993, and it has been hypothesized that an increase in bare areas due to loss of shoal grass led to increases in turbidity from wind-induced erosion. However, data on the annual average light penetration, estimated from permanent monitoring platforms in the upper lagoon, indicate that light is limiting (i.e., below minimum requirements) for shoal grass in the southern portion of the upper lagoon, but is above minimum light requirements for shoal grass in the northern portion (Militello et al., 1997).

As a result of the decrease in light penetration resulting from the brown tide in the Upper Laguna Madre, biomass of the seagrass *Halodule wrightii* (shoal grass) growing at depths >1.4 meters has decreased by more than 60% between a period just before the onset of the brown tide (1988) and a few years thereafter (1993) (Onuf, 1996). Primary production in the upper lagoon used to be dominated by shoal grass, but is now dominated by phytoplankton (Militello et al., 1997).

Some areas of shoal grass growing at depths >1.4 meters have disappeared because the amount of light reaching the shoal grass was not sufficient to support leaf photosynthesis at a level that could maintain the substantial below-ground root biomass. However, not all areas of shoal grass growing in deep water that were predicted to be stressed by the brown tide have actually become unvegetated (Onuf, 1994). Apparently, the stressed shoal grass can persist in part by reclaiming nutrients from dying grasses. Maintenance of the grass at this level of stress is considered tenuous. It is anticipated that additional portions of these deeper areas in the upper lagoon are very susceptible to any additional stress that would further decrease light penetration, and could easily be lost. In Galveston Bay, most shoal grass was lost when anthropogenic changes such as urban development, waste water discharges, and dredging decreased light penetrations to levels similar to the levels measured at 1.4 meters in the upper Laguna Madre. Even though light levels were similar, the additional stress of epiphytic growth (algae growing on the leaf surfaces of the seagrasses) that occurred in Galveston Bay was apparently sufficient to push the seagrasses past a threshold of survivability (Dunton, 1994).

The effects of brown tide in the Lower Laguna Madre appear to be limited to the winter, when the passage of cold fronts can move water from the upper to the lower lagoon (Brown et al., 1997). The magnitude of effect is much lower than in the upper lagoon, with chlorophyll levels associated with the transported brown tide 50% to 70% lower than those observed in the upper lagoon.

2.4.4 Changes in seagrasses

Quammen and Onuf (1993) report that the very high salinities common in the Laguna Madre in the mid-1940s and before excluded seagrasses from much of the lagoon. Apparently, fish and wildlife descriptions of the Laguna Madre from the early 1920s did not mention seagrasses (Brown et al., 1997). As described above, salinities exceeding 100 parts per thousand (ppt) in the upper lagoon and 60 ppt in the lower lagoon were common in the mid-1940s. Of the seagrasses common in Laguna Madre, the species *Halodule* (shoal grass) is the most salinity tolerant, and it survives only for 28 days at 70 ppt (McMahan, 1968, in Quammen and Onuf, 1993). Thus, lagoon salinities in the mid-1940s would have frequently exceeded the long-term tolerances of most seagrass species. In addition, wide and sudden fluctuations in salinity were common under extreme hypersaline conditions, for instance as the result of runoff from major rain events. Large salinity variations are difficult for most species to adapt to (Britton and Morton, 1989).

The moderation in salinity to levels that have remained below 50 ppt in the upper lagoon and have rarely exceeded 40 ppt in the lower lagoon (Quammen and Onuf, 1993) apparently fostered the expansion of seagrasses into previously unvegetated areas of the Laguna Madre. Several studies, summarized by Brown and Kraus (1997), document an extension of seagrasses northward in the lower lagoon between 1955 and 1976.

A progressive shift in species composition and relative abundance to include wider distribution and increased abundance of seagrasses that are less salinity tolerant, has also been documented in the Lower Laguna Madre during the period of moderated salinities. Bottom coverage by shoal grass (*Halodule wrightii*) decreased from 82% in 1965 to 33% in 1988, while coverage by manatee grass (*Syringodium filiforme*) increased from 9% to 27%, and coverage by turtle grass (*Thalassia testudinum*) increased from

1% to 7% (LaRoe et al., 1995; Quammen and Onuf, 1993). Increases in manatee and turtle grass distribution in the lower lagoon, since salinity has moderated, are consistent with their lesser tolerance of high salinities (Quammen and Onuf, 1993). These species are not yet common in the Upper Laguna Madre, and while the upper lagoon has on the average, higher salinity than the lower lagoon, these species are also slow to disperse compared to *Halodule* (Quammen and Onuf, 1993; LaRoe et al., 1995).

The first documentation of losses of seagrasses, in a study by Merkford (1978, in Brown et al., 1997), was for the deep portions of Port Isabel Bay, just northwest of Port Isabel in the Lower Laguna Madre (Figure 2-5), where 96.5 square kilometers (km^2) of seagrasses were lost between 1966 and 1974. The area of bare bottom increased to 190 km^2 in 1988, representing an increase since 1965 of 280% (Quammen and Onuf, 1993). This loss was also concentrated in the deep portions of Port Isabel Bay west of the GIWW. During this same period, about 330 km^2 of shoal grass were lost, being replaced in part (about 190 km^2) by less salinity-tolerant species (especially manatee grass, *Syringodium filiforme*, and turtle grass, *Thalassia testudinum*). Changes in coverage by seagrasses observed between the mid-1960s and the late 1980s are as follows (from Quammen and Onuf, 1993).

Upper Laguna Madre	**1967**	**1988**
Shoal grass (Halodule wrightii)	120 km^2	250 km^2
Other species	none	none
Bare bottom	210 km^2	80 km^2
Lower Laguna Madre	**1965**	**1988**
Shoal grass (Halodule wrightii)	550 km^2	220 km^2
Other species	70 km^2	260 km^2
Bare bottom	50 km^2	190 km^2

By 1988, seagrasses covered about 730 km^2, or about 75% of the subtidal bottom of the Laguna Madre (Onuf, 1996). This represents about 80% of the seagrasses along the Texas coast (Quammen and Onuf, 1993). Brown and Kraus (1997) have shown that the area of seagrass loss in the Lower Laguna Madre (the bare area that had been vegetated by shoal grass in 1965) generally follows the one meter contour line, and is thus probably associated with inadequate light levels in deeper water. This is also where the GIWW crosses a natural deep area (the "bathymetric depression") in the lower lagoon, and for that reason, is the area where consistent cross-channel currents transport turbid waters across the GIWW.

A more recent study in the southern portion of the Lower Laguna Madre (Brown et al., 1997) documents some continued changes in distribution and abundance of seagrasses. Since total areas of vegetated and unvegetated areas were not presented in this study, direct comparison to the earlier works for evaluation of trends in seagrass coverage is difficult. However, based on percent occurrence, the extent of area covered by turtle grass (*Thalassia testudinum*) appears to have continued to increase between 1988 (Onuf, 1996a) and 1994-95 (Brown et al., 1997) (17% to 7%). Over the same period, the percent occurrence of shoal grass (*Halodule wrightii*) decreased (66 to 34%). It should be noted, however, that the earlier study

(Onuf, 1996a) was for the entire Lower Laguna Madre, while the recent study (Brown et al., 1997) surveyed only the southern half of the lower lagoon.

Sampling of seagrasses is continuing in an effort to model the effects of dredge deposits on the distribution and productivity of seagrasses. Sampling is being conducted for the Interagency Coordination Team by the University of Texas, Texas A&M University and the Texas Parks and Wildlife Department.

2.5 ENDANGERED SPECIES AND NESTING GROUNDS

Threatened and endangered species identified by the U.S. Fish and Wildlife Service (1997) as occurring in the counties adjacent to the Laguna Madre are listed in Table 2-3. The few threatened and endangered species which utilize marine environments as habitat, and thus could potentially be encountered within the Laguna Madre-Padre Island system being considered in this report, can be categorized into two groups: (1) shorebirds and (2) aquatic mammals and reptiles. Knowledge of these species and their likely habitats of occurrence is important to this evaluation, to assure that no alternative for dredged material application would directly harm a listed species, or compromise its habitat within the lagoon. The possibility of using dredged material to create habitat, or extend or enhance existing habitat for a threatened or endangered species, is also a special consideration.

2.5.1 Threatened and endangered shorebirds

Brown Pelican. This is a Gulf Coast species that utilizes the abundant fisheries of the Laguna Madre. In the 1981 USFWS report, these birds were considered as only formerly known in the area and found elsewhere along the Texas coast. However, the return of this species has included the coastline of the Laguna Madre.

Piping Plover. Although this bird ranges all along the Atlantic coast, it is found along the Laguna Madre during winter migrations. The species uses the coastal shorelines and inland salt ponds as feeding grounds. Beach disturbance has been attributed to the reduction in species numbers (TPWD, 1997).

2.5.2 Threatened and endangered aquatic mammals and reptiles

West Indian manatee. This large aquatic mammal has been sighted within the Laguna Madre and the mouth of the Rio Grande River. These sightings are rare, probably due to the species' sensitivity to water conditions. Extreme winter cold temperatures and hypersaline conditions may restrict the presence of manatees in the Laguna Madre.

Sea turtles. These reptiles spend most of their adult life in the waters of the Gulf of Mexico and feed on seagrasses. Thus, the barrier islands and coastal shores of the Laguna Madre provide habitat for nesting. Juvenile sea turtles, especially the green turtle, frequent the Laguna Madre to forage. The combination of beach development and incidental catch by fisherman has reduced sea turtle numbers.

2.5.3 Nesting grounds

The Laguna Madre region contains the greatest diversity of avian species in the United States because of the abundant fisheries, range of habitat types, range of climate, and low level of human intrusion (Coste and Skoruppa, 1989). Bird nesting areas are present throughout the Laguna Madre region. Sensitive bird rookeries are concentrated around the submerged seagrass beds located predominantly in the Lower Laguna Madre between the south end of Padre Island and the Laguna Atascosa National Wildlife Refuge, as well as in Baffin Bay through the north end of Padre Island (Bacak-Clements, 1997). The brown pelican does not presently nest within the Laguna Madre. The nearest nesting site is Brown Pelican Island, adjacent to the Corpus Christi Ship Channel. No endangered or threatened bird species nest on the dredged material islands in the Laguna.

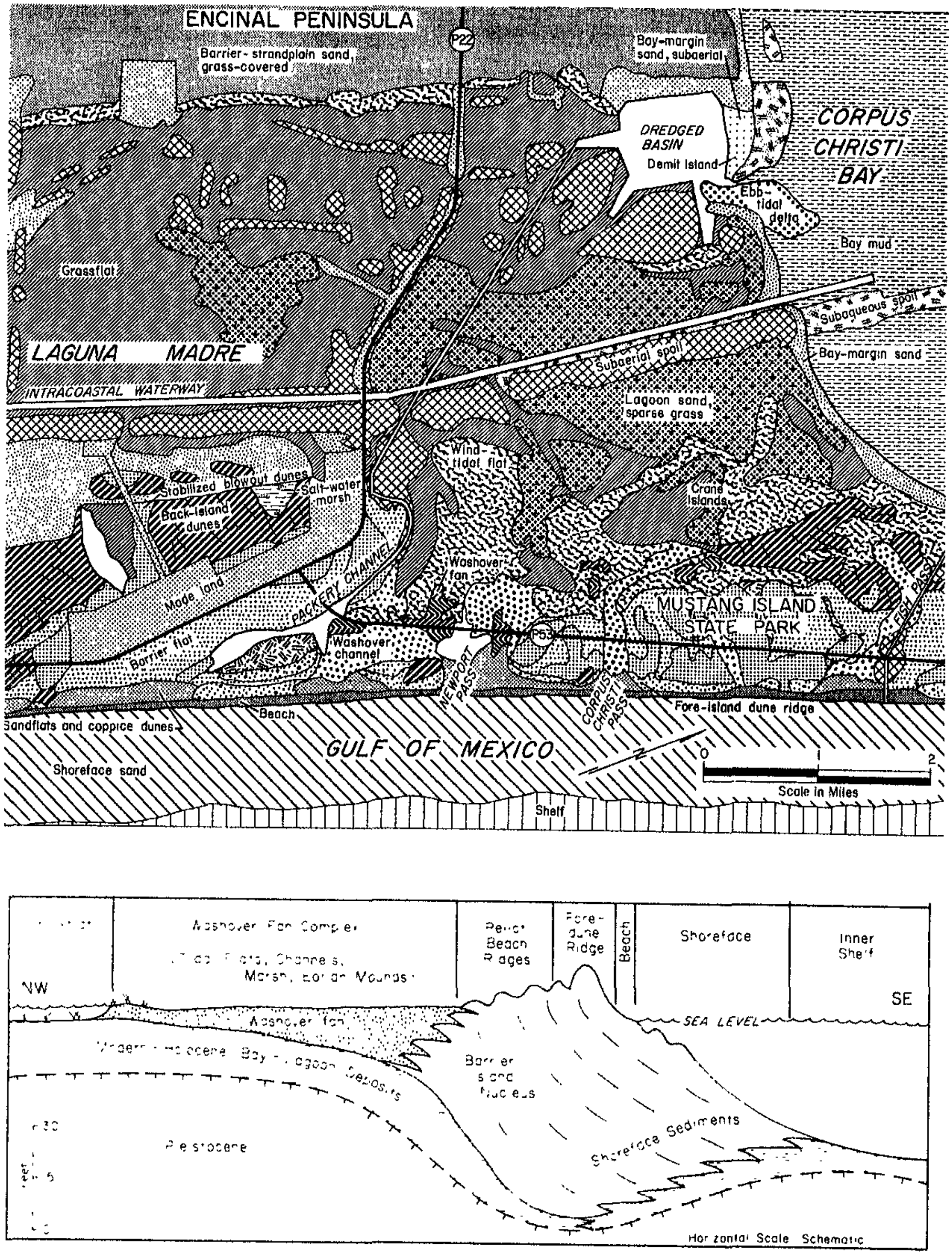
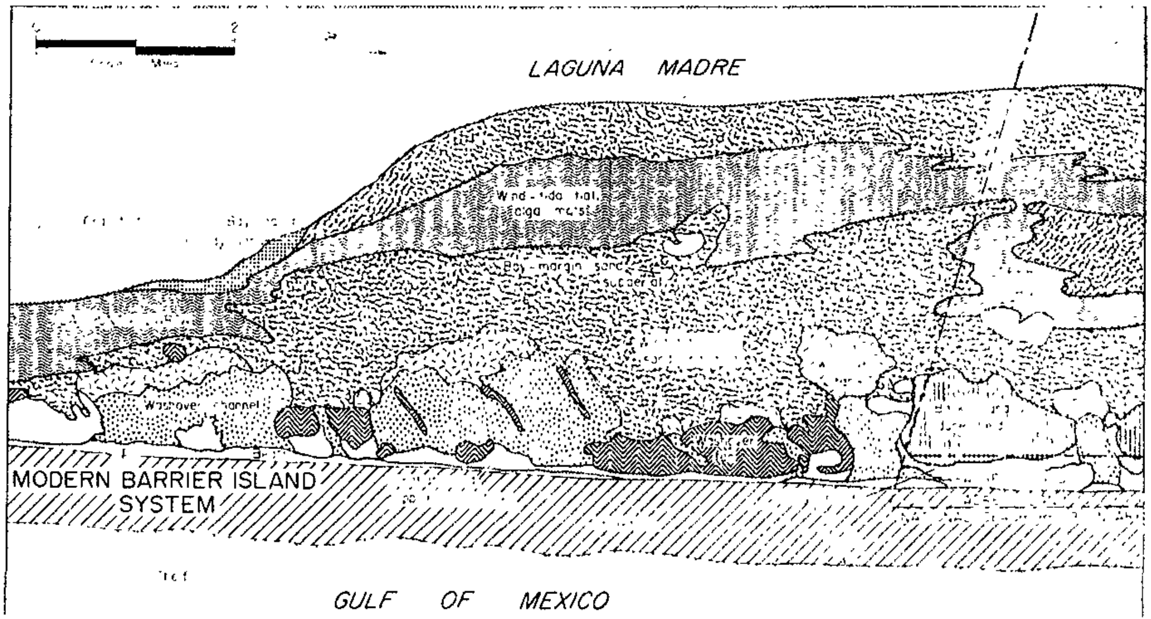


Figure 2-1: Upper Laguna Madre Schematic Plan View and Cross-Section into Lagoon

(After Brown et al., 1976)



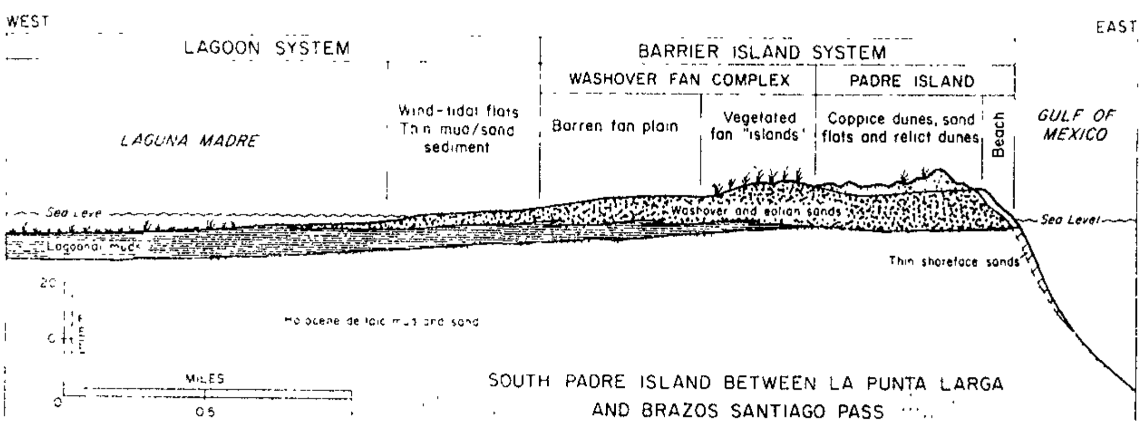


Figure 2-2: Lower Laguna Madre Schematic Plan View and Cross-Section into Lagoon

(After Brown et al., 1980)

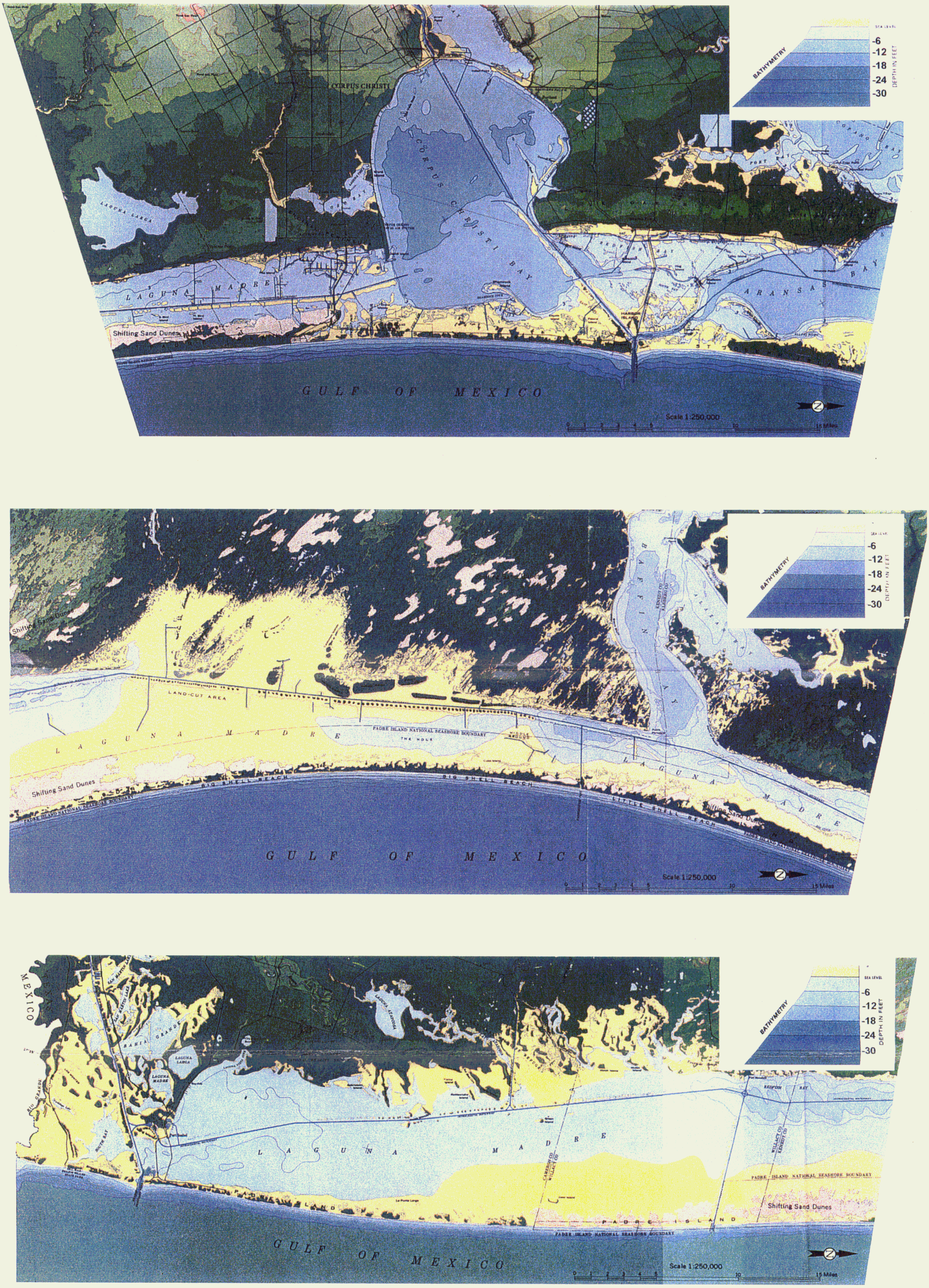


Figure 2-3: Bathymetry of Laguna Madre

(Source: Brown et al. 1976, 1977, 1980)

Coastal Environments, Inc.
Baton Rouge, Louisiana

Figure 2-4: Schematic cross-section of major Laguna Madre environments

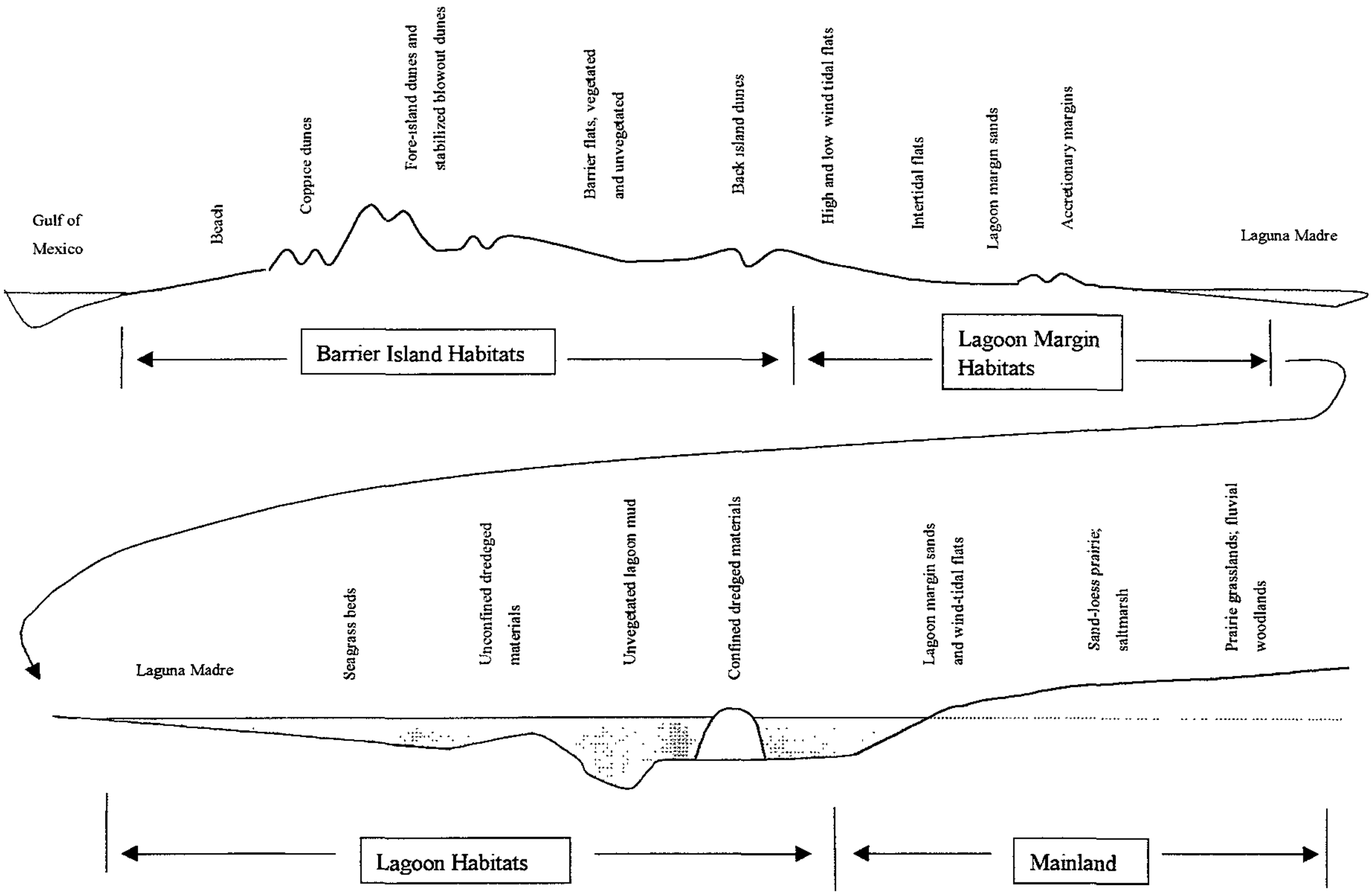


FIGURE 2-5 DISTRIBUTION OF SEAGRASS BEDS AND DREDGED MATERIAL DEPOSITS IN THE LAGUNA MADRE

See pocket in back of report for this oversized map.

TABLE 2-1. WATER QUALITY CONDITIONS, LAGUNA MADRE AREA

Summarized from the 1990 Texas Water Quality Inventory (TWC, 1990)

Water body	Segment	Problems or significant potential problems
Laguna Madre	2491	Occasionally slightly depressed dissolved oxygen levels; elevated fecal coliform levels near the Arroyo Colorado; elevated fecal coliform levels near the GIWW. Periodic elevation of total phosphorus and inorganic nitrogen; and frequent elevation of orthophosphorus.
Corpus Christi	2481	Partially closed for oyster harvesting due to fecal coliform.
Baffin Bay	2492	None.
Arroyo Colorado	2201	Supersaturated dissolved oxygen levels occur periodically due to algal metabolism. Nutrient levels and chlorophyll a levels are elevated occasionally, and the high productivity contributes to pronounced elevated dissolved oxygen levels.
Brownsville Ship Chnl	2494	None.
South Bay	2493	Partially closed for oyster harvesting due to fecal coliform.

Summarized from the 1996 Espey, Huston and Associates study (EHA, 1996).

Segment	Water	Sediment	Tissue	Source
	Parameter levels elevated or of concern			
Arroyo Colorado	Total dissolved solids, total suspended solids, volatile solids	Total organic carbon	Metals, chlordane, DDT	Davis et al., 1995 (as cited in EHA, 1996)
Baffin Bay	Dissolved metals (cadmium, copper zinc)	Chromium, copper, lead		Barrera et al., 1995 (as cited in EHA, 1996)
Lower Laguna Madre (vicinity of Port Mansfield Pass and Port Isabel	Dissolved metals (cadmium, copper, lead). Some values exceed Texas and EPA water quality standards.			TWDB database
Upper Laguna Madre	Total organic carbon and zinc (samples from winter of 1993)			USACE dredging database

TABLE 2-2. HABITAT CHARACTERISTICS

Habitat type	Materials/ geomorphology	Hydrology	Flora/fauna	Habitat value
Barrier Island				
Beaches	Fine sand and shell, cusps, nearshore bars, wide backbeach, 100 to 200 meters (m)	Wave dominated	Purslane, morning glory, backshore dune grasses, sea oats; backshore bird nesting, invertebrates, crabs, clams, ghost shrimp	Lagoon and backbarrier pond protection, feeding, nesting
Coppice dunes - Lower Padre Island	Fine sand, dunes 0.5 to 1.5 m, discontinuous, associated washover fans, sand source for flats	Freshwater reservoir, storm washover	Scattered vegetation, sea oats on fringe, morning glory, purslane; bird nesting	Partial lagoon protection, feeding and nesting
Fore-island dunes, stabilized blowout dunes - Upper Padre Island	Fine sand, dunes 6 to 12 m, continuous ridge	Freshwater reservoir	Sea oats, bitter panicum, morning glory, seacoast bluestem; song birds, small mammals, reptiles	Lagoon protection, feeding, and nesting
Vegetated flat - Upper Padre Is.	Fine sand and shell, 0.5 to 1.5 m, local ponds and marshes	Freshwater reservoir	Shrubs, grasses and vines; rodents, reptiles, waterfowl	Lagoon protection, feeding and nesting
Unvegetated flat - Lower Padre Island	Fine sand, 1 to 2 m, isolated small dunes, deflation surface	Tidal or storm inundation; fringed by fresh or brackish ponds	Unvegetated except near ponds	Partial lagoon protection
Back-island dunes	Fine sand, hummocky, mobile dunes (various types), blowout complexes, sand source for flats	Tidal or storm inundation; fringed by fresh or brackish ponds	Unvegetated flats to some grasses and shrubs; rodents, birds, reptiles	Partial lagoon protection
Lagoon margin				
High wind-tidal flats	Fine sand and mud, mobile dunes, lower than one meter MSL	Seldom flooded (5% of time)	Poorly vegetated, isolated algal mats	Backbarrier protection
Low wind-tidal flats	Fine sand and mud, no dune formation, inter-laminated	Infrequently flooded	Sporadic, thin algal mats	Backbarrier protection
Intertidal flats	Fine sand, clay and mud, inter-laminated, evaporite clasts	Flooded daily except during major wind events	Extensive algal mats	Backbarrier protection
Lagoon margin sands	Fine sand, narrow deposit, ripple to sand wave bed forms	Submerged to 0.9 meters; waves and tidal currents active	Sparse marine grass, algal mats; fish, shellfish, wading birds	Backbarrier protection; mod.-high bio productivity, species diversity
Accretionary margins	Fine sand, berms, narrow beach, spit-like features	Infrequently flooded	Vegetated	Bird nesting
Serpulid reefs	N/A	Submerged 0.6 to 0.9 meters	Formerly annelid worms	Resistant buffer to erosion; low species diversity
Seagrass beds				
Seagrass beds	Muddy sand with shells	Submerged to 1.2 meters with some exposure at low tides or wind forcing	Shoalgrass, clovergrass, widgeongrass, turtlegrass, manateegrass; fish, shrimp, crabs, clams, snails, invertebrates	High biological productivity; high species diversity

Table 2-2 Habitat characteristics (continued)				
Habitat type	**Materials/ geomorphology**	**Hydrology**	**Flora/fauna**	**Habitat value**
Unvegetated lagoon mud				
Unvegetated lagoon mud	Sandy mud to mud	Submerged 1.2 to 2.7 meters	Sparse grasses; fish, shellfish	Mod.-high biological productivity, high species diversity
Dredged material				
Unconfined placement areas	Sand, shell, and mud	Infrequent flooding; waves and tidal currents active	Shrubs and grasses; bird feeding and nesting, finfish	Mod. to high biological productivity; nesting habitat
Confined placement areas	Sand, shell, and mud	Infrequent flooding	Levee-margin vegetation - shrubs and grasses; bird feeding, nesting	Nesting habitat
Mainland				
Lagoon margin sands and wind-tidal flats	Fine sand, clay, and evaporites	Occasionally flooded	Grasses and algal mats near GIWW; reptiles	Upland protection
Sand-loess prairie	Sand and silt	Occasional fresh water marsh	Bunch grasses and scattered live oak; rodents, snakes, fowl	Supports commercial fauna
Saltmarsh	Sandy silt and mud	Frequently flooded	Grasses; mammals, waterfowl	Upland buffer; mod.-high bio productivity; nesting habitat
Prairie Grasslands	Mud and sand forming flat to rolling uplands; relict eolian ridges and sand sheets; cleared - cultivated areas	Freshwater reservoir, some irrigation	Diverse grasses, shrubs, and trees: bluestem, Indiangrass, mesquite, hackberry, oaks; small mammals, bird nesting	Non-halophytic plant and animal habitat
Fluvial Woodlands	Clay, silt and sand forming flat to rolling uplands; cleared - cultivated and grazing areas	Freshwater reservoir, some irrigation; seasonally flooded, inland stream channels	Diverse assemblages, e.g. water tolerant plants/trees to hardwoods: oak, ash, hickory, pecan, elm; abundant mammals, reptiles, fowl	Non-halophytic plant and animal habitat

TABLE 2-3. THREATENED AND ENDANGERED SPECIES IN THE LAGUNA MADRE AREA

Species (common name)	Species (Scientific name)	Status	Counties Of Occurrence
Birds			
American peregrine falcon	*Flaco peregrinus anatum*	E	N, Kl, Ke, W, Ca
brown pelican*	*Pelecanus occidentalis*	E	N, Kl, Ke, W, Ca
northern aplomado falcon	*Falco femoralis septentrionalis*	E	Kl, Ke, W, Ca
piping plover*	*Charadrius melodus*	T	N, Kl, Ke, W, Ca
cactus ferruginous pygmy owl	*Glaucidium brasilianum cactorum*	C	Ke, W, Ca
snowy plover*	*Charadrius alexandrinus*	C	N, Kl, W, Ca
Arctic peregrine falcon	*Falco peregrinus tundrius*	T	N, Kl, Ke, W, Ca
bald eagle	*Haliaeetus leucocephalus*	T	Kl, Ca
Mammals			
jaguarundi	*Felis yagouaroundi*	E	N, Kl, Ke, W, Ca
Gulf Coast hog-nosed skunk	*Conepatus leuconotus texensis*	C	N, Kl, Ke, W, Ca
West Indian manatee	*Trichechus manatus*	E	N, Ca
ocelot	*Felis pardalis*	E	N, Kl, Ke, W, Ca
Plants			
South Texas ambrosia	*Ambrosia cheiranthifolia*	E	N, Kl, Ca
Texas ayenia	*Ayenia limitaris*	E	Ca
slender rush pea	*Hoffmannseggia tenella*	E	N, Kl
black lace cactus	*Echinocereus reichenbachii* var. *albertii*	E	Kl
Reptiles			
hawksbill sea turtle	*Eretomochelys imbricata*	E	N, Kl, Ke, W, Ca
Kemp's ridley sea turtle*	*Lepidochelys kempii*	E	N, Kl, Ke, W, Ca
leatherback sea turtle	*Dermochelys coriacea*	E	N, Kl, Ke, W, Ca
green sea turtle*	*Chelonia mydas*	T	N, Kl, Ke, W, Ca
loggerhead sea turtle*	*Caetta caretta*	T	N, Kl, Ke, W, Ca

* Typically found in marine areas including: barrier islands, shorelines, estuaries or in the waters of the Laguna Madre. The hawksbill and leatherback sea turtles are typically found in the open Gulf of Mexico, not in the Laguna Madre.

Federally Threatened (T), Endangered (E), and Candidate (C) Species Listed by the U. S. Fish & Wildlife Service as of August 27 for Nueces (N), Kleberg (Kl), Kenedy (Ke), Willacy (W), Cameron (Ca) Counties, Texas (USFWS, 1997).

3. DREDGING OVERVIEW

3.1 HISTORIC DREDGING PRACTICES

The Gulf Intracoastal Waterway (GIWW) in Texas extends from the Sabine River to Brazos Santiago Pass. The first segment (Brazos River to West Galveston Bay) was initiated in 1905. The second segment (Galveston Bay to the Sabine River) was completed in 1934. The segment from Corpus Christi to Brownsville, through the Laguna Madre, was completed in 1949. The channel is currently maintained with approximate channel dimensions of 3.66 meters deep (12 feet) and 38.1 meters of bottom width (125 feet). Dredging is accomplished using cutterhead hydraulic dredges.

Between 1950 and the present, the USACE has dredged approximately 38.23 million cubic meters (50 million cubic yards) from the Upper Laguna Madre and an almost identical 37.465 million cubic meters (49 million cubic yards) from the Lower Laguna Madre (Figure 3-1). Thus the yearly average for both the Upper and Lower Laguna Madre has been approximately 764,600 cubic meters (one million cubic yards). The maximum dredging in any one year was higher in the Upper Laguna Madre with approximately 4.6 million cubic meters (6 million cubic yards), versus 2.3 million cubic meters (3 million cubic yards) for the Lower Laguna Madre.

Figure 3-2 displays the dredge volumes versus distance according to the Corps of Engineers ranges for two segments of the Laguna Madre: Corpus Christi to the Mud Flats and Port Isabel to the Mud Flats. With the exception of the Corpus Christi Bay area, most of the dredging in the upper end has occurred from the region south of South Bird Island to the Land Cut, at approximately 382,300 cubic meters (500,000 cubic yards) per project. High dredged material volumes per project characterize Lower Laguna Madre. The Port Isabel to Stover Point segment undergoes rapid shoaling, and dredging recurs every 18 to 24 months (Brown et al., 1997). As Lower Laguna Madre has higher volumes per project, and both Upper and Lower Laguna Madre produce about the same amount of dredged material, more dredging is *required per unit volume in the Upper Laguna Madre.*

Dredged material volumes exceed 764,600 million cubic meters (1 million cubic yards) per project in three areas: the area north of Port Isabel to Stover Point, the area near Arroyo Colorado Cutoff, and the area south of Port Mansfield. These locations of high deposition are for the most part related to the natural, wind-driven circulation patterns in the Laguna Madre (Brown et al., 1997; Militello et al., 1997).

3.2 HISTORIC PLACEMENT PRACTICES

Placement locations. Since the inception of a dredging program for Laguna Madre, the locations of disposed dredged material has been mapped in numerous publications (White et al., 1983; 1986, 1989, NOAA, 1995). Figure 2-5 shows the locations of dredged material as mapped from GIS data provided by the State of Texas. Most of the dredged material was placed near the GIWW as unconfined low-lying subaerial deposits ("dredged material islands") or was confined within retention levees formed with coarser dredged materials.

The material now being dredged is primarily silt and clay and is very “soupy” (characterized as "fluid muds"). Once discharged, the material tends to flow rather than stack; and if it does produce bottom deposits, these are easily eroded by wind-driven currents and waves. Emergent fine material is also subject to wave and wind erosion. There are two exceptions to this pattern: where confined placement sites are available, and, in the northern end of the Upper Laguna Madre, some material is dredged that has a higher clay content and less interstitial water, and is more "stackable", i.e., it will tend to stay in place when discharged. Where confined disposal sites are available, they are perceived to be the preferred locations. The ICT has been formed to investigate which disposal options are actually preferable.

Placement methods. The early dredging of the Laguna Madre produced extensive quantities of relatively coarse materials. Some of this was side cast to form dredged material islands and other material was worked with draglines to form levees enclosing large (greater than 40 hectares, or 100 acres) retention areas designed to receive future dredged material. The latter occurs as subaerial deposits on the east side of the GIWW, primarily to the north and within the Land Cut. Additional confined areas have not been constructed due to lack of sufficient supertidal land with the foundation characteristics suitable for supporting a levee system. However, the capacities of the existing leveed disposal areas are not restricted because the levees can be elevated when the need arises.

Current placement typically involves conveyance through a 61-centimeter (24-inch) diameter pipe (though other sizes have been used), with discharge into open water or onto islands without confinement. Material is placed at least 244 meters from the channel centerline (Brown et al., 1997).

During the maintenance dredging cycle of 1994-95, several techniques were used in which placed material was either subaerial or subaqueous, confined or unconfined (Brown et al., 1997). Of the different placement methods used, only unconfined placement was specifically evaluated in the study conducted for the U.S. Army Corps of Engineers Galveston District by the Conrad Blucher Institute (Brown et al., 1997, Militello et al., 1997).

In the Lower Laguna Madre, unconfined subaqueous placement of dredged material to the west of the GIWW experienced a substantial amount of erosion within 8 to 13 months of deposition (Brown et al., 1997), though consolidation also occurred to some degree. At one transect, deposition that had initially increased bottom elevation by 22.86 centimeters had eroded to +7.62 centimeters within eight months. Unconfined dredged material placed to the east of the channel in the upper lagoon in December (1994) had almost completely eroded within six months, apparently largely due to the passage of winter fronts (Militello et al., 1997).

Only minimal information on other placement approaches is available.

- Subaqueous confined placement was used in 1994-95 to limit how much the dredged material spread, with the intention of creating shallow submerged habitat that would support seagrass. One such area was built in Lower Laguna Madre in the center section of placement area 234 (Brown et al., 1997). The submerged levees were constructed of dredged material 0.6 to 0.8 meters from bottom with additional material confined on the lee side, westward of the GIWW. The relative success or failure of this levee was not fully known (McLellen, 1997).

- Two areas of subaqueous shallow mounding were created during the 1994-95 dredging cycle. These mounds were near the northern ends of placement areas 233 and 234 (Brown et al., 1997) (Figure 2-5). The mounds were to be about 60 meters by 60 meters, with reduced water depth that would support seagrass. The areas were planted and are being monitored by Ken Dunton of the University of Texas Marine Science Institute, with Gulf of Mexico Program funding.

  At the shallow mounding site near the northern end of the Lower Laguna Madre, a one foot accumulation of deposited sediment remained up to 13 months after deposition (Brown et al., 1997). *Apparently this location is less subject to erosional forces than the open-bay placement* sites that are adjacent to the high depositional reaches of the GIWW, where sediments were often almost completely eroded within 8 months of placement.

- Confined subaerial placement was used in 1994-95 to create emergent habitat in the middle of placement area 233 (Brown et al., 1997). The emergent levee had a design crest height of 0.3 to 0.5 meters above water level. Depth profiles at the site of confined placement with emergent levees showed probable slumping and erosion of the levees on the west side of the site (away from the GIWW), although confinement was apparently maintained (Brown et al., 1997). No other monitoring information on these experimental sites is currently available.

3.3 IMPACTS OF CURRENT PLACEMENT PRACTICES

3.3.1 Sources of information

Merkford (1978, in Brown et al., 1997) and Onuf (1994) attributed the loss of seagrasses in the Lower Laguna Madre to dredging impacts. This conclusion was based largely on the proximity of the region of seagrass loss to the GIWW channel. As a result of the widespread concern regarding the possible association of dredging and unconfined bay placement on lagoon seagrasses, the Laguna Madre Interagency Coordination Team (ICT) has recommended and authorized numerous studies and modeling efforts, most of which are currently ongoing.

A two and one half year monitoring study of the Laguna Madre is being conducted by the Conrad Blucher Institute at Texas A & M University-Corpus Christi. This study is focusing on open-bay placement of dredged material, with the objectives of examining:

- encroachment of sediment on seagrass beds;
- resuspension of sediment in dredged material placement areas;
- reduction of light within the water column;
- loss of material from placement sites;
- transport of dredge material back into the GIWW; and
- evaluation of the relationship between hydrodynamic forcing and sediment movement.

Reports on the first year of study in both the Upper and the Lower Laguna Madre, covering the 1994-95 maintenance dredging cycle, were just recently published (Brown et al., 1997; Militello et al., 1997). Other significant ongoing efforts include a multidisciplinary effort to develop an integrative model for seagrass productivity in the Laguna Madre, for which an interim report is available (Cifuentes et al., 1997); a study of the effects of open bay placement on habitat use by fish, for which an interim report is also available (Sheridan, 1996); and a study of benthic macroinfaunal responses to dredged material placement, for which a final report was recently published (Espey, Huston & Associates, 1997).

These works plus numerous other reports and publications in the literature are used here to briefly establish what is known about the relationship between dredging activities and ecological changes in the Laguna Madre, and to characterize the boundaries of what is not yet well understood.

3.3.2 Fate of dredged material

Most of the sediments that are removed by maintenance dredging are fine-grained and therefore the material does not settle out quickly, but creates a turbid plume. However, most of the material from dredging (or sediment resuspension) typically settles within 24 hours (Brown et al., 1997; Militello et al., 1997). Studies of the 1994-95 maintenance dredging cycle in the lower lagoon showed that both the average and the range in variability in turbidity, measured as total suspended solids, increased during dredging. Average concentration of total suspended solids was about three times as high during dredging as just before dredging (Brown et al., 1997). Maximum values often exceeded 400 mg/l during dredging, compared to a maximum around 200 mg/l prior to dredging. Average turbidities returned to normal within a year after dredging.

After this initial impact, the settled material is subject to ongoing erosion. One indication of this effect is that, overall, about 420,530 cubic meters (550,000 cubic yards) of dredged material remains in unconfined placement areas to the west of the high depositional reach of the GIWW in Lower Laguna Madre, amounting to a sediment accumulation about 0.3 to 0.6 meters (1 to 2 feet) deep. This is compared to a total of about 4.6 million cubic meters (6 million cubic yards) that have been dredged from this reach from 1945 to 1991 (Brown et al., 1997), indicating substantial loss of dredged material from unconfined bay placement sites.

The recurrence of high turbidities in the Laguna Madre for up to a year after dredged material placement apparently reflects the continued greater susceptibility of unconfined dredged material to resuspension compared to natural bottom or to older, consolidated deposits (Militello et al., 1997). The effect appears to diminish after a year, apparently because dredged material susceptible to resuspension has eroded by then (Brown et al., 1997).

Recent studies have shown that eroded dredged material can wash back into the GIWW and contribute to the accumulation of material requiring dredging. Monitoring of a 1994 dredging project indicated much of the wash back and shoaling in the GIWW occurs within the first 8 to 10 months (Militello et al., 1997; Brown et al., 1997). The wash back appears related to wave-driven resuspension and wind and tidal current transport into the GIWW. The same studies also demonstrated that portions of some seagrass beds were actually physically smothered by mobile dredged material.

3.3.3 Direct loss of bottom habitat

Sites where dredged material is placed (whether confined or unconfined) typically represent areas of bottom habitat that are disturbed and often lost upon initial placement of dredged sediment. The affected habitats include seagrass bottoms and unvegetated bottoms that support benthic invertebrate communities.

In some cases, notably with the sandier sediments removed during initial dredging of the GIWW, material was stacked to become subaerial, forming dredged material islands. Many of these islands are used by nesting and foraging water and shore birds. Thus, there is development of viable habitat (e.g., bird habitat) that differs from the original habitat (e.g., benthic habitat).

In other situations where disposed sediments remain subaqueous, there is the same initial loss of the original bottom habitat. However, if the sediments are sufficiently stable, recolonization of dredged material by invertebrates can take place relatively rapidly, often within one year. Thus, some ecological value can be regained, even if original habitats (e.g., seagrass beds) are not restored. As placement areas are reused in subsequent maintenance dredging cycles, any restored habitat would again be disturbed, restarting a recovery cycle.

3.3.4 Effects on light attenuation

<u>Importance of light penetration</u>. It has been hypothesized that dredged material placement has an adverse impact on seagrasses, by causing increased turbidity and reduced light penetration; in turn, the seagrass impacts would be adverse to finfish, shellfish and migratory birds (Diaz and Kelly, 1994). Recent studies have neither proven nor disproven this hypothesis, and it is clear that turbidity conditions and seagrass conditions in the Laguna Madre are influenced by many factors, including but not limited to dredge material placement.

Attenuation of light from the surface through the water column is one of the main factors determining the depth at which plant life can exist in the water (i.e., the photic zone). In marine systems, the photic zone is commonly defined as the depth to which 1% of surface light penetrates (Kirk, 1994). This definition is based on the photosynthetic needs of marine algae. In comparison, seagrasses have about 60% to 80% of their biomass in roots and rhizomes (Dunton, 1994), and photosynthesis in the leaves must support the food and respiratory needs of this below-ground biomass. To maintain the greater level of photosynthesis needed to support its biomass, seagrasses require more light than planktonic algae.

Some estimates of the light requirements of seagrasses have been made. In response to wide-spread losses of seagrasses, the State of Florida set water clarity standards at 10% of surface irradiance to protect seagrasses (Brown et al., 1997). To enable restoration of submerged aquatic vegetation, the Chesapeake Bay Program adopted guidelines for light attenuation coefficients (k) not to exceed 2.0/meter at one meter water depth, which corresponds to slightly less than 20% surface irradiance (moles of photons per meter squared per second) (Batiuk et al., 1992). It has been estimated that the dominant seagrass in Laguna Madre, shoal grass requires about 18% surface irradiance to survive (Dunton, 1994; Onuf, 1996b). This value can be used to estimate the depths at which shoal grass will persist in the Laguna based on prevailing turbidity conditions.

Factors affecting light penetration. Two dominant factors affecting light penetration are total suspended solids and chlorophyll concentration (Cifuentes et al., 1997; Batiuk et al., 1992). In Upper Laguna Madre, degree of light attenuation is primarily affected by chlorophyll concentration, which accounts for about 65% of the variation in light attenuation (Militello et al., 1997). This reflects the current predominance of brown tide in the upper lagoon. As in the lower lagoon, elevations in total suspended solids were observed in the upper lagoon due to wind events of sufficient magnitude, and in association with dredging (Militello et al., 1997). However, no significant differences could be documented in mean light attenuation due to dredging compared to pre- or post-dredging periods. Apparently, the significance of chlorophyll concentrations in controlling light attenuation masks any differences that may be contributed by dredging disturbances in the upper lagoon.

In Lower Laguna Madre, chlorophyll concentration plays a lesser role in controlling light attenuation. Brown tide can be advected from the Upper to the Lower Laguna Madre in the winter during the passage of cold fronts, but associated chlorophyll levels are substantially lower than those which occur in the upper lagoon (Brown et al., 1997). More than 80% of the variation in light attenuation in the lower lagoon can be explained by total suspended sediment concentrations (Brown et al., 1997).

Turbidity in the Laguna Madre. Total suspended solids concentration and turbidity in the Laguna Madre are largely a result of the resuspension of bottom sediments. The Laguna Madre is a shallow system with both water movement and reworking of bottom sediments largely driven by wind (Brown et al., 1997; Militello et al., 1997). There is a strong correspondence between wind speed events, increases in turbidity and increases in light attenuation in the lower lagoon (Brown et al., 1997). The effects of tidal currents on resuspension of sediment are minimal, although once suspended, tidal currents can transport sediments. Sediments can also be resuspended by water-displacement currents induced by passage of vessels, and by trawling (Militello et al., 1997).

In addition to the marine processes, natural flood and/or flood control waters in the Arroyo Colorado, North Floodway and Baffin Bay convey freshwater, sediments and nutrients episodically toward the Laguna Madre. Baffin Bay is characterized as conveying the least amount of floodwater to the Laguna Madre of the three basins (Brown et al., 1977). Nutrient loadings of total phosphorus under non-storm conditions were cited as excessive in Baffin Bay and the Arroyo Colorado by Shew et al. (1981).

The occurrence and distribution of turbidity in the Laguna Madre is variable, and is controlled primarily by the presence or absence of seagrasses, and secondarily by type of local sediment, with turbidities generally lower over sand than over mud bottoms (Breuer et al., 1962 in Brown et al., 1997). That is, higher turbidities usually occur in unvegetated areas with muddy sediments.

There is a feedback relationship between loss of seagrasses, wind-induced resuspension of sediments (including dredged material), and light attenuation. Sediments in seagrass beds require about 50% higher wind velocities for resuspension compared to unvegetated areas (Brown et al., 1997). As a result, maximum light attenuation is much lower in the seagrass bed, and wind speed accounts for only about 35% of the variation in light attenuation. In a nearby unvegetated area, wind speed explained 91% of the variation in light attenuation, and maximum light attenuation observed was more than three times as high as in the vegetated area (Brown et al., 1997). If an area becomes unvegetated, its sediments will be much more susceptible to resuspension at prevailing wind speeds. Occurrences of high light attenuation will increase, and likelihood of successful revegetation of the area will diminish.

Dredging and seagrasses. Increasing turbidities and greater light attenuation follow the onset of dredging activities. Light levels measured in an area without seagrasses adjacent to a dredged material placement area in the Lower Laguna Madre were about 50% to 60% below that needed by seagrasses (about 18% surface irradiance for shoal grass) (Brown et al., 1997). It was estimated that the effects of dredging in suppression of light to below 18% surface irradiance at the bottom extended for about eight months after dredging.

Brown et al. (1997) did not document a significant increase in bare (unvegetated) area between the initiation of a maintenance dredging cycle in 1994, and about one year after dredging in 1995. They did find a "substantial, but not statistically significant decrease" in biomass of turtle grass between the pre- and post-dredging periods. This could have reflected an unusually favorable growing season just prior to the pre-dredging survey in 1994, as the decrease in 1995 was back to levels comparable to that observed in 1974 and 1988.

In their report on the first year of a two and one half year study, Brown et al. (1997) put forward an alternate hypothesis, in which the seagrass losses are due to increased light attenuation resulting from suspended sediments introduced by hurricanes and breaching of the barrier island, and accentuated by the relatively rapid rate of sea level rise that was documented for the Laguna Madre at Port Isabel after 1965. Analysis of historic maintenance dredging showed that sedimentation rates were about twice the average rate for the 6-year period following Hurricane Beulah, a Category 5 hurricane that did substantial damage to South Padre Island and the surrounding region in 1967.

It also has been shown in the Upper Laguna Madre that passage of major hurricanes (Category 3 or higher) significantly increased volumes of sediment that must be maintenance dredged, compared to intervals without hurricanes (Militello et al., 1997). This implies a concomitantly higher level of suspended sediments and greater light attenuation for a sufficient period of time to potentially affect seagrasses in deeper water, where they are most likely to be closest to marginal light levels.

Deeper regions of the Lower Laguna Madre (e.g. the west side) also have finer-grained sediments than the areas to the east of the GIWW, and once seagrasses declined there, sediments would be more easily resuspended, leading to greater turbidities, lower light levels, and further losses of seagrasses in a feedback loop. Since this is the area of natural (cross-channel) current circulation, wind-generated turbidities would be preferentially transported through this region.

3.4 FACTORS IMPACTING BENEFICIAL USE

Many factors have the potential to impact possible beneficial uses of dredged material in the Laguna Madre. Certain of these factors are entirely outside the scope of the current report, including: benefit/cost assessment of dredging; cost of placement; overall environmental acceptability of dredging and placement. Other factors, as discussed below, have been considered at a reconnaissance level.

3.4.1 Characteristics of dredged material

Table 2-1, presented earlier in this report, summarized historical water and sediment quality concerns for the Laguna Madre. Concerns have been identified with respect to total organic carbon and metals from agricultural and urban-associated runoff in the vicinity of Arroyo Colorado and Baffin Bay.

In order to provide current data for use in evaluating beneficial dredging alternatives and ODMDS disposal, the U.S. Environmental Protection Agency funded sampling of 26 locations along the GIWW (Figure 3-3). Reference site sampling was done in the vicinity of the Port Mansfield and Brazos Island Harbor ODMDS, Ref 1 and Ref 2, respectively; for the Corpus Christi ODMDS, previously obtained data were utilized. EPA funded laboratory analysis of the samples through the U.S. Army Corps of Engineers, Galveston District (EHA, 1998). Results have been summarized in a separate document (LWA, 1998).

The GIWW sampling was conducted in water depths ranging from 3.14 to 6.13 meters, at an average 4.7 meters. The two offshore Reference Sites were sampled in water depths of 13.8 and 14.3 meters, respectively. The DO readings, for all stations, ranged from 2.75 to 7.64 mg/l, averaged 5.62 mg/l and decreased with depth. The lowest concentration occurred at LM-5, north of Baffin Bay. pH readings averaged 8.52 and ranged from 8.02 to 8.94. Overall, salinities ranged from 23.5 to 40.1 parts per thousand and averaged 31.4 parts per thousand; the readings did not vary markedly at each site. The highest salinity was observed in the ULM at BA-2, near the Bird Islands; no significant salinity stratification was observed. Water temperatures ranged from 21.7 to 29.8°C and averaged 27.7°C.

Chemical analyses were conducted on water, elutriate, and sediment samples. Solid phase bioassays and bioaccumulation studies were also conducted on sediment from six test stations, on reference control sediment, on a true control (clean beach sand), and on background levels in test organisms. The following summarizes the results and interpretations of these studies:

1) The sediment composition (Table 3-1) is primarily silt and fine sand size particles, with mean particle size averaging 0.08 mm and ranging from 0.01 to 0.21 mm. The finer materials occur between LM-5 and LM-9 in the lower half of the Upper Laguna Madre, and between LM-11 and LM-15 in the upper half of the Lower Laguna Madre.

2) The TPH, phenols, PCBs, and pesticides analyses were below detection limits in all sediment samples. TOC was analyzed by method 413.2, an oil and grease determination with an MDL of 5.0 mg/kg. Espey, Huston and Associates (EHA, 1998) reported one TOC sample, LM1 (Corpus Christi Bay) with detectable levels, at 7.2 mg/kg. In general, the highest concentrations of most metals in sediment occurred at stations with a predominantly silt/clay (i.e., fine-grained) sediment type, especially at the mouth of Baffin Bay south toward the Land Cut (LM-6 through LM-9) (Table 3-2). Effects Range Low (ERL) and Effects Range Medium (ERM) developed by Long et al. (1995) were used for comparison to these results. LM-6 had the highest sediment concentration of five of the ten metals (chromium, copper, lead, nickel and zinc), though none exceeded ERLs. LM-8 had the highest sediment concentration of barium, cadmium and mercury. The concentrations of arsenic in sediments at stations LM-11 and BA-6 and of cadmium at stations LM-8 and BA-4 substantially exceeded both respective ERLs and ERMs. Thus, these parameters could represent cause for concern. The sediment concentrations of mercury slightly exceeded only the ERL at stations LM-8 and LM-12. As with the metals results, the stations located in the vicinity of Baffin Bay toward the Land Cut had the highest total sulfide and ammonia sediment concentrations, associated with finer grain sizes.

3) For water and elutriate, lead, zinc and copper exceeded EPA Marine Water Quality Criteria. Zinc exceeded acute criteria in the water column at five stations: LM6, BA3, LM8, LM9 and LM16; as with sediment, most of the stations are in the vicinity of Baffin Bay and south toward the Land Cut. One (LM16) is in the Lower Laguna Madre between the North Floodway Outlet Channel and Arroyo Colorado. Lead exceeded chronic criteria in both the water and elutriate samples at LM2, and exceeded chronic criteria at LM4 (elutriate) and LM11 (water). Note that all metals measured in water samples are total, not dissolved, concentrations, while metals measured in elutriate samples are dissolved concentrations because of the elutriate preparation methodology (EHA, 1998). Therefore, minor apparent exceedances of criteria in water samples may not be exceedances in fact, as the criteria are for dissolved concentrations. All stations, including reference sites, exceeded EPA's marine criteria for copper in both water and elutriate (except LM2 elutriate). EPA's marine criteria for copper, unlike other metals, is significantly more stringent than the Texas marine criteria: acute = 2.9 vs. 16.27 ug/l; chronic = 2.9 vs. 4.37 ug/l, respectively. Using the Texas standards, most stations

would still exceed the chronic criterion, but not the acute criterion. Copper is discussed further below.

4) The ultraclean results suggested that most of the routine sampling was reliable. Only potential contamination of TPH was indicated. As discussed below, future analysis of copper samples should include the latest USGS methods for dissolved results.

5) The solid phase bioassay results indicated that, except for sampling station BA-4 (North Floodway Outlet Channel), there appears to be no potential for environmentally unacceptable lethal impacts on benthic organisms from the disposal of any ULM or LLM sediments. Survival of organisms exposed to test sediments in the solid phase bioassays was not significantly different from survival of organisms exposed to the solid phase of the reference control. The exception was sampling station BA-4, where there was a significant difference between mean survival rates of *Ampelisca abdita* in material from BA-4 and in the Reference Control material.

6) Uptake of barium at BA-1 was shown in *M. nasuta* relative to reference control tissues. The concentrations of barium (BA-1, BA-5, and BA-6) and chromium (BA-5) in tissues of *N. virens* were significantly higher than in the reference control and true control, but not compared to background tissue concentrations. Significant ecological impacts would not be expected from the bioaccumulation exhibited by these bioaccumulation studies.

To further examine potential spatial patterns of concern, Table 3-2 summarizes for each station all analytical results that could provide evidence of a potential concern. Sediment analyses are summarized according to the number of detected metals (of 10 tested) in the sediments and the number for which a sediment quality guideline was exceeded. The water and elutriates are summarized according to the number of analytes above EPA marine criteria. The bioassay toxicity results are summarized based on the occurrences of survival differences greater than 10% (20% for amphipods) when compared to the reference sediment results. Similarly, the tissue work is summarized according to the number of analytes detected and the number that were significantly higher than the reference control.

As indicated above, placement of dredged material from adjacent the North Floodway Outlet Channel (BA-4) could impact organism survival. Another station, LM-8, near the mouth of Baffin Bay, shows the greatest number of exceedances of criteria or guidelines for metals in all three media tested (sediment, water and elutriates). However, the metals showing exceedances were different for each medium tested (arsenic and cadmium for sediments, copper and zinc in water, and copper and lead in elutriate). With the exception of copper, sampling results support the observation that metals in the system tend to be associated with the finer grained sediments that occur predominantly near the mouth of Baffin Bay.

Levels of both total and dissolved copper exceeding EPA and Texas Marine Water Quality Criteria are common historically in the Laguna Madre (see Lind and Ratzlaff, 1976; EHA, 1996). In addition, numerous EISs in the Gulf region (as cited in EPA, 1994) report data showing levels of copper which are sometimes higher than the water quality criteria. However, Presley et al. (1988) state that most of these data overstate actual concentrations by factors of 10 to 1000 or more. They cite the conclusions of Bruland (1983), that only in recent years have sets of dissolved trace metal data for seawater been obtained that conform to known physical and biological oceanographic parameters; and state that few seawater samples from the Texas-Louisiana shelf have been analyzed for dissolved trace metals with the care required to lend confidence to the data.

Two reliable data sets do exist for Gulf conditions near the shelf; these are reported in Boyle et al., 1984. One set extended from Miami, around the tip of Florida and across the Gulf to near Bay Saint Louis, Mississippi. Only three metals were detected in the open gulf, and these were found at nearly constant concentrations despite the wide geographic study range: cadmium - 0.0005 ppb; copper - 0.082 ppb; nickel - 0.011 ppb. These values are much lower than typically reported (e.g. in Gulf region EISs) where, for example, copper levels of 20 ppb or more are cited.

The second data set reported in Boyle et al. (1984), near the Mississippi coastline, found higher concentrations, averaging 0.5 ppb for copper and nickel and 0.02 ppb for cadmium; similar values are reported for the Mississippi River plume in Shiller and Boyle (1983). The second Boyle data set was taken in the northwestern Gulf, mostly in water depths of 100 meters of more; the results were similar to those discussed above.

Because of sampling and analytical difficulties, apparent high levels of copper are not certain indicators of a water quality problem in Laguna Madre. Rather, they indicate a need for further investigation, and a need for ultraclean sampling using the latest methods from USGS for the most accurate estimates of dissolved concentrations.

Ultimately, copper not withstanding, and BA-4 a possible exception, the results and interpretations of Laguna Madre data indicate that there are no generic constraints to use of GIWW sediment for beneficial use. Any potential constraints would have to involve a specific application or location where a sensitive receptor was known to exist. At this level of effort, no specific limiting locations or receptors have been identified.

3.4.2 Dredging and placement technology

Dredging in Laguna Madre is open to all size cutterhead dredges, unless they are limited by the 3.66 meter (12 foot) depth of the channel and the shallow, generally less than 1.8 meters (6 foot), depth of the rest of the lagoon. The typical dredge capacity allows for a pumping distance of up to 3,000 meters (10,000 feet). Thus placement distances without booster pumps are limited to slightly less than about 3.2 kilometers (2 miles).

In general, the ability to pump dredged material to placement sites is limited by pump efficiency. There is generally a greater than 10% loss of efficiency attributed to the use of one booster pump. Using booster pumps in tandem increases that loss logarithmically rather than linearly. Therefore, there is a limit to the distance dredged material can be pumped, depending, in part, on the material, size of the pipeline, horsepower of the dredge and pumps used, and water content of the slurry (per USACE comments to draft of this report).

Pumping over long distances also poses environmental concerns. Pumping of dredged material through pipelines any appreciable distance from the GIWW would in most instances involve crossing fragile, shallow habitats such as seagrass beds, wind-tidal flats, algal flats, or even dune complexes. Damage to such habitats could result from placement and movement of the pipeline, and from the track equipment that would be needed to move the pipeline. Impacts might be reduced by one-time construction of permanent pipelines. Unless the outfalls of such pipelines were permanent placement areas, additional temporary pump facilities would still be required to convey material to the final placement location. In time, permanent dredge pipes would wear out and need to be replaced, and they would pose navigation hazards and could impede water circulation in the shallow waters (per USACE comments to draft of this report).

While hydraulic cutter-head dredges are typically used in the Laguna Madre, numerous dredging technologies exist that present potential alternatives.

- Hopper dredges are commonly used to dredge the passes in Laguna Madre. While most hopper dredges require too deep a draft to be used for dumping material in the shallow lagoon, this technology could be considered for transporting material to ocean dredged material disposal sites (ODMDS) in the Gulf (refer to Figure 1-2). Barge transport is also a possibility.

- Jet spray technology represents an alternative to end-of-the-pipe discharge, and can be used to add controlled thickness (i.e., very thin layers) of sediments to habitats that require or would benefit from controlled sediment additions.

- The USACE also has been evaluating the potential applications of water injection dredging technologies (injection of water into sediment, causing the sediment to liquefy and be carried away by the current). Specific application in the Laguna Madre has not been reviewed in this study.

The nature of most Laguna Madre dredged material is generally that if discharged without confinement, it will disperse and, if mounds are formed, these will erode. Relatively little of the material will stack and remain in place for a period longer than 1 year. This raises environmental concerns (turbidity; larger footprint of overall impact) and economic concerns (wash back may lead to increased frequency of maintenance dredging). Most important for this study, it means that many alternatives for beneficial use of the material will require that the material be contained or confined.

Several options could be considered for confining dredged materials in order to achieve beneficial use. The most obvious is to use placement areas where confinement levees already exist. A different approach would be to mine containment material from existing dredged material placement areas. The following concepts apply to this approach.

- The existing emergent dredged material islands that are not leveed were mostly formed during the early dredging of the GIWW and have a high sand content. The material has had time to dewater, consolidate, and stabilize. Some of these islands could be considered for mining of sediments suitable for development of containment levees. Primary consideration would be given to islands that are not highly utilized by nesting birds.

- One concept would be to scoop out the middle of an island and create a containment levee along the margins. New material would be placed within the island. This would produce a higher island. If the material were to remain in place (e.g., not be eroded by wind), the relatively high-elevation habitat might prove suitable for brown pelican nesting.

- Another concept would be to excavate material from areas where there is a relatively long island, breaking the area up into smaller islands and possibly reducing predator occurrence. The material would be used to create new islands in the form of a ring. The outer slopes would be graded to be suitable for wading birds. The island interior would be filled by dredged material to produce an emergent island with potential nesting habitat.

Other options for confinement include: dredging the GIWW to a greater depth in order to obtain (presumed) coarser material beneath the channel (and also to extend the time between dredging cycles); dredging a wider channel to get coarser material; importing shell, sand, rock or other stable materials; and using specialized engineering structures such as geotextile tubes and pillows. In all cases, the presumption is that islands would be designed to have a size, form and isolation that is beneficial to habitat.

Note that the discussions above are concerned with placement in the Laguna Madre and environs. For this study, consideration has not been given to the export of material to distant locations (e.g. sand and gravel pits along the coast, which might be reclaimed with dredged material). The economic issues raised by such long-distance placement are outside the scope of the current study and, based on experience elsewhere, their use would imply the justification of a very large dollar investment in beneficial use. The assumption here is that, if funds are not a limiting factor, this would simply provide more potential for achieving beneficial use (or placement with fewer impacts) at locations relatively close to the GIWW.

3.4.3 Recent example of ICT evaluation

The ICT has recently (December 1996, and meetings in 1997) reviewed alternatives for discharge of dredged materials in upcoming maintenance from the shoal area at GIWW mile 660. Most of the alternatives were not very far removed from normal operations; most involved designated placement areas in the lagoon or the Gulf, reflecting only a change in the standard of using the closest placement area. Several alternatives specified beneficial use, including such alternatives as creation of gulfside beaches, increasing bay bottom to those necessary for seagrass beds, creating submergent berms to reduce shoreline erosion, and placement at development areas (Holly Beach). Costs were estimated in a separate report by Gahagan & Bryant (GBA, 1997).

Alternatives had to comply with an ICT set of 12 evaluation criteria, including issues of dredging frequency, costs, planning, environmental considerations, navigation impacts, beneficial use, and engineering feasibility. A matrix was used to illustrate the relative impact of alternatives. Evaluation of alternatives by the ICT was consistent with some of the recommendations in Brown et al. (1997) and Militello et al. (1997), such as not placing dredged material adjacent to the channel in regions of high shoaling, where cross-channel currents tend to erode the sediments and re-deposit them in the channel. The ICT methodology will be used in this report to the extent it is appropriate.

3.5 EXISTING ODMDS SITES

Existing ODMDS sites could potentially be used for placement of material dredged from the Laguna Madre. Three ODMDS sites exist in the area: Corpus Christi, Port Mansfield, and Brazos Island Harbor, located off the north, middle and south portions of the planning area, respectively (refer to Figure 1-2, where the three off-shore sites are referred to as "dump site", "disposal areas" and "dump site" respectively). All have been in use for many years and have been given final ODMDS designation. Site Management Plans exist for each ODMDS. The basic characteristics of these ODMDS sites are presented in Table 3-3 and considered further below.

The ODMDSs were originally selected according to five general and eleven specific criteria identified in the Ocean Dumping regulations (40 CFR 228.5 & 228.6), one of which was consideration to the type of sediment typically removed from the channels. As discussed in Section 4.6, an initial screening required of all dredged material to be placed at the ODMDS is sediment type; if it is not the same as the disposal site, then additional testing is required.

One issue that should be considered is that the sediments from the Laguna Madre are slower to settle and more easily resuspended than the sands previously deposited at the existing ODMDS sites. Thus, they are more likely to erode and to cause turbidity plumes. In addition, the fluid mud sediments are likely to spread more on initial deposition than sands. The Port Mansfield ODMDS is proximal to the Mansfield Cut Underwater Archaeological District, which is excluded from the designated ODMDS site and protected by a buffer zone. The extent of buffer needed might be greater if muds are deposited at this site.

Figure 3-1: Laguna Madre Dredging Volumes Since 1950

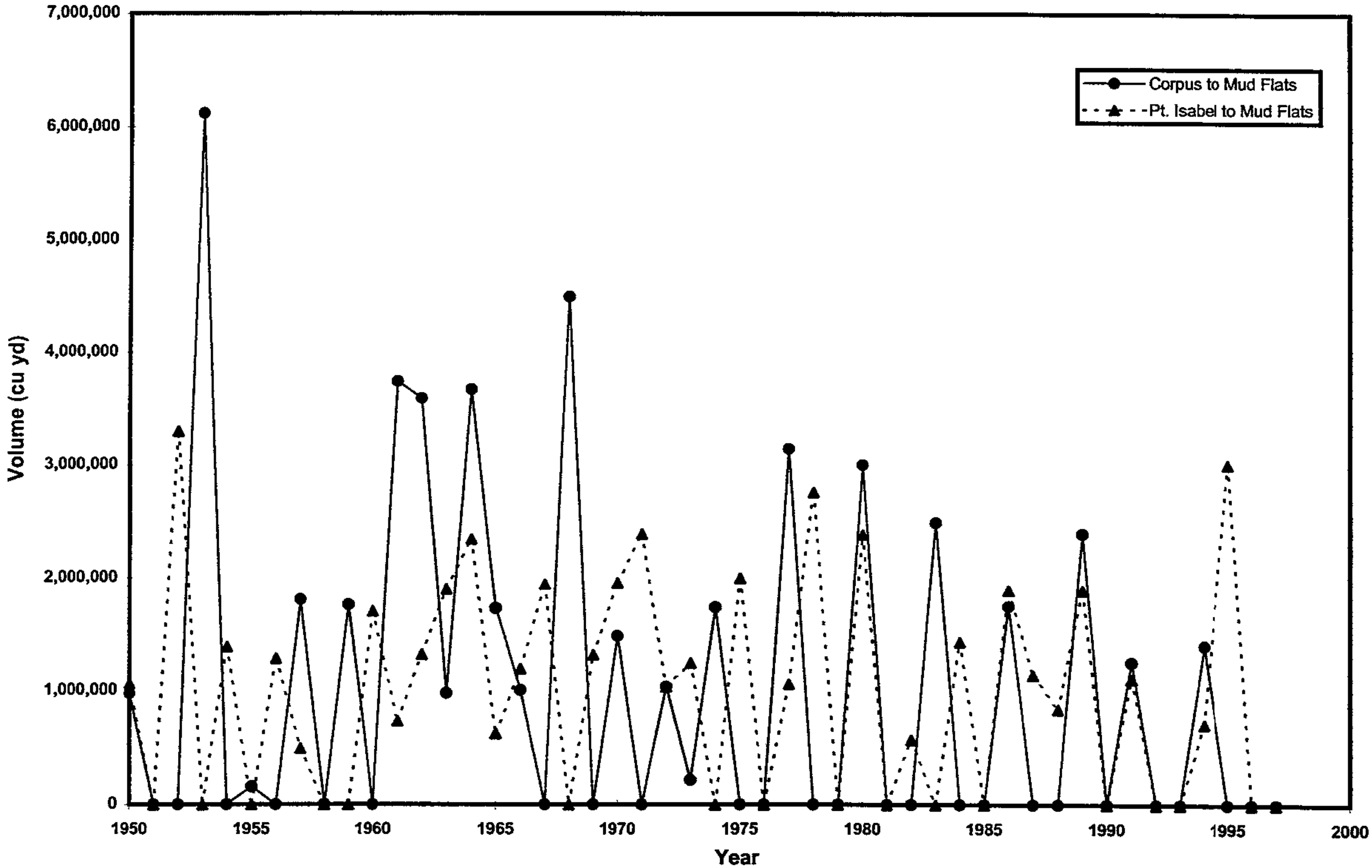
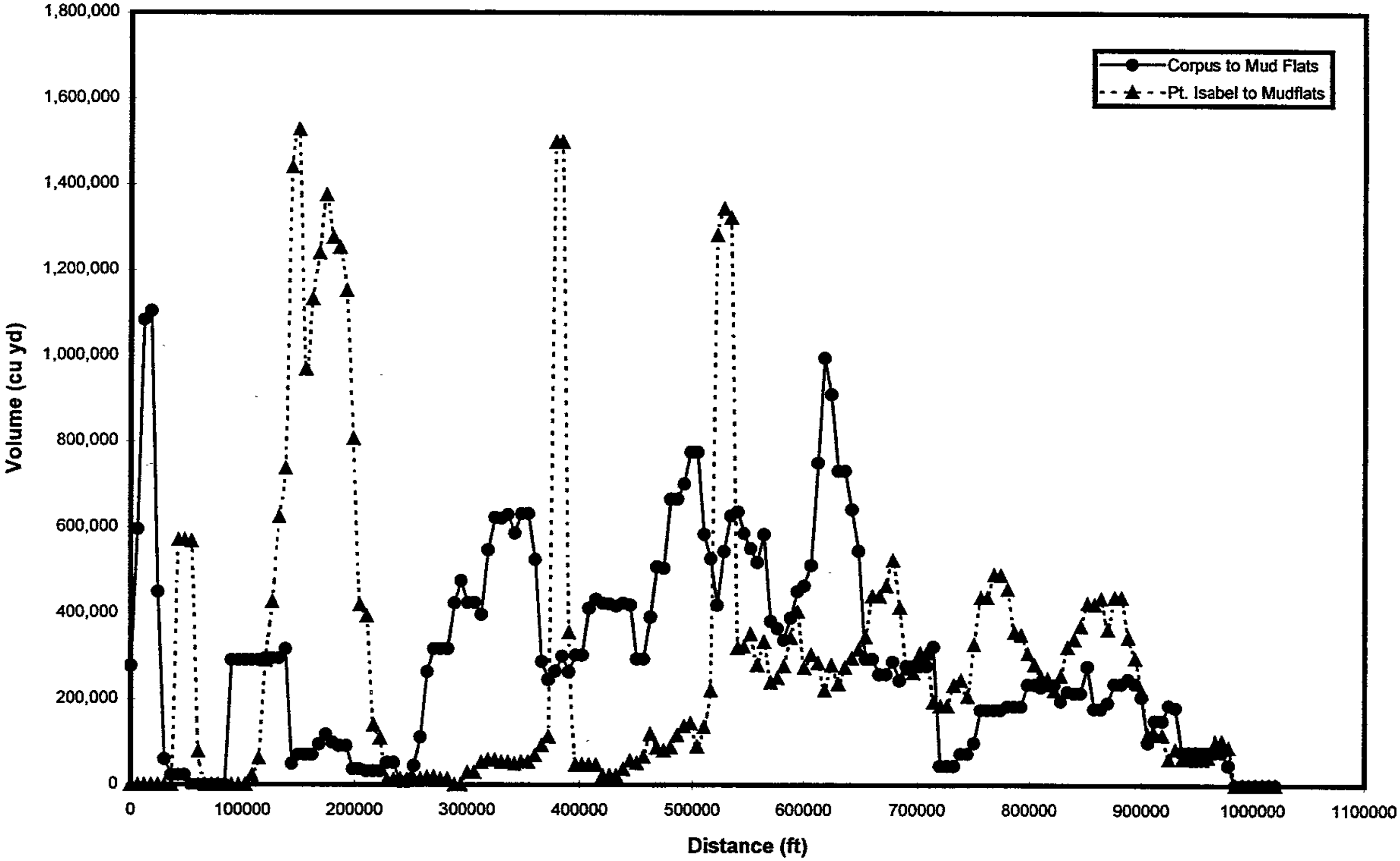


Figure 3-2: Laguna Madre Dredging Volumes and Distance



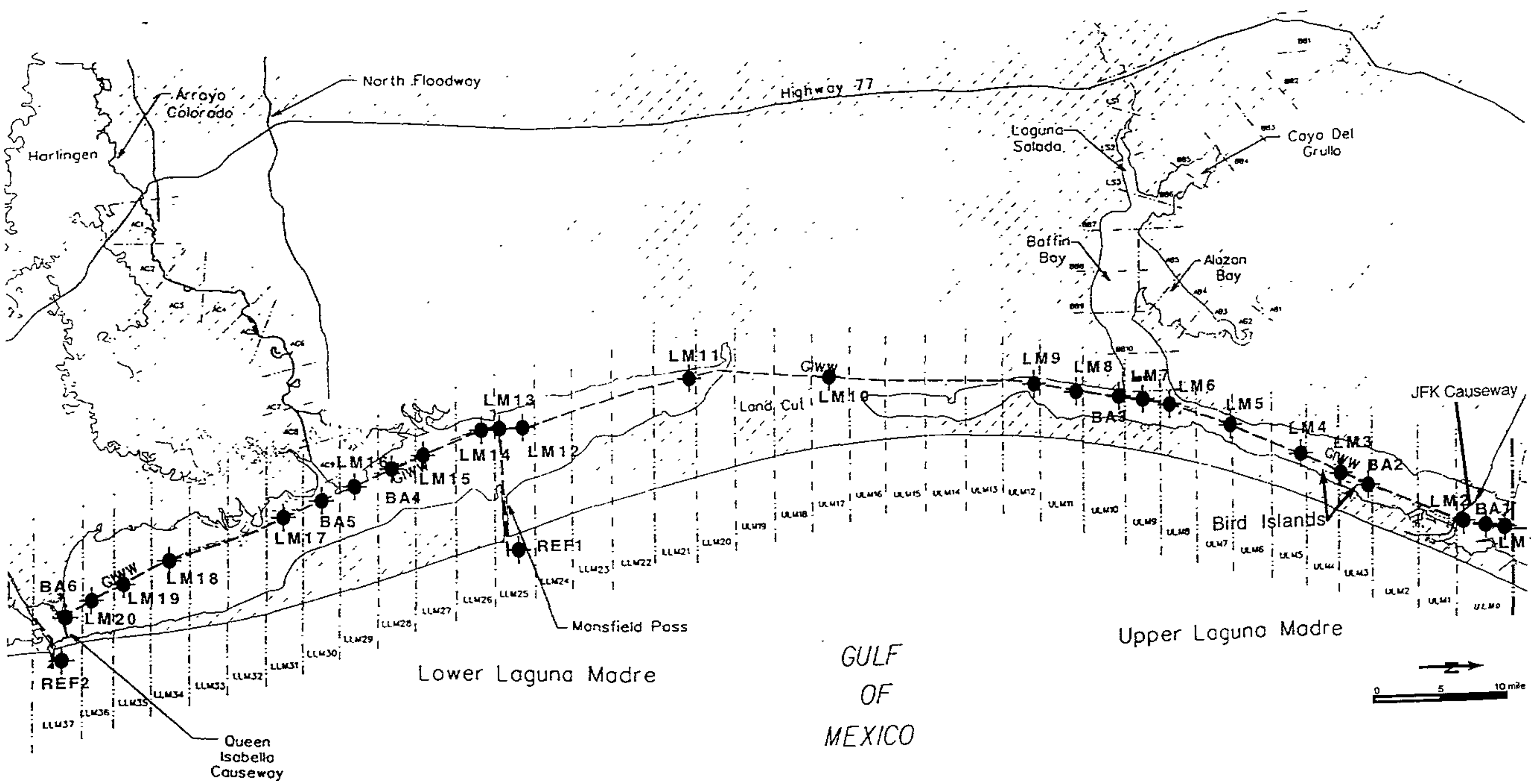


Figure 3-3. Location of sampling sites

TABLE 3-1. SUMMARY OF GRAIN SIZE RESULTS (JUNE 1997), LAGUNA MADRE, TEXAS

Sample	Mean Size (mm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Sediment (%)
LM1	0.16	1.9	79.3	17.7	1.1	100
BA1	0.19		83.7	8.9	7.4	100
LM2	0.15	10.2	51.2	30.4	8.2	100
BA2	0.10		52.6	40.3	7.1	100
LM3	0.15		79.9	18.4	1.7	100
LM4	0.15		65.1	28.7	6.2	100
LM5	0.01		4.9	85.5	9.6	100
LM6	0.01		4.9	85.5	9.6	100
LM7	0.01		9.7	74.9	15.4	100
BA3	0.05		2.6	85.0	12.4	100
LM8	0.01		15.3	68.0	16.7	100
LM9	0.01		11.2	83.8	5.0	100
LM10	0.20	0.2	75.3	19.5	5.0	100
LM11	0.01		14.6	79.6	5.8	100
LM12	0.01	2.5	18.1	68.2	11.2	100
LM13	0.01	0.5	7.9	70.3	21.3	100
LM14	0.02		34.6	57.8	7.6	100
LM15	0.06		32.2	64.1	3.7	100
BA4	0.11		56.0	42.2	1.8	100
LM16	0.16		54.6	45.4		100
BA5	0.06		36.6	60.8	2.6	100
LM17	0.06		34.8	61.5	3.7	100
LM18	0.01		18.0	73.4	8.6	100
LM19	0.02		26.8	65.0	8.2	100
LM20	0.17		65.8	34.2		100
BA6	0.08	0.6	52.3	39.8	7.3	100
Ref 1	0.21	2.1	96.0	1.7	0.2	100
Ref 2	0.12		67.4	20.8	11.8	100
CCREF	0.18		82.9	11.4	5.7	100
Average	0.08	2.6	41.1	51.1	7.7	
Maximum	0.21	10.2	96.0	85.5	21.3	
Minimum	0.01	0.2	2.6	1.7	0.2	

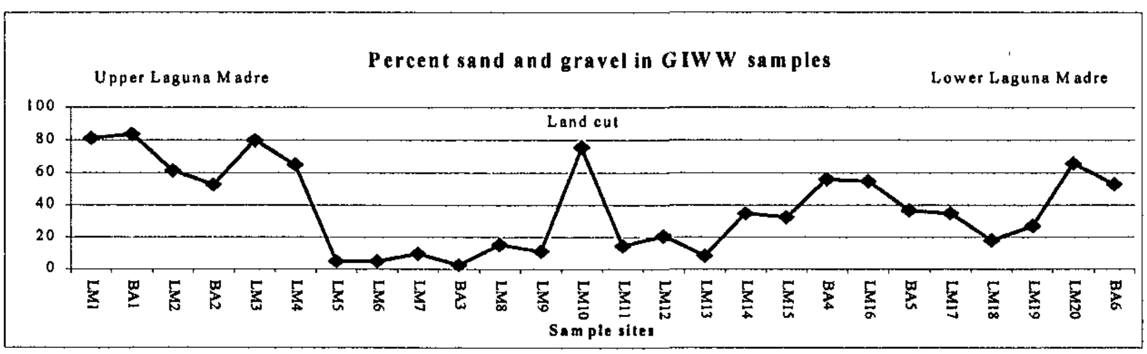


TABLE 3-2. CHARACTERISTICS OF DREDGED MATERIAL (JUNE, 1997), LAGUNA MADRE, TEXAS

Upper Laguna Madre | Lower Laguna Madre

Analysis	LM1	BA1	LM2	BA2	LM3	LM4	LM5	LM6	LM7	BA3	LM8	LM9	LM10	REF1	LM11	LM12	LM13	LM14	LM15	BA4	LM16	BA5	LM17	LM18	LM19	LM20	BA6	REF2
Sediment - Metals																												
# above guidelines[1]	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	1	0
Water - Metals																												
# above EPA water quality criteria	1	1	2	1	1	1	1	2	1	2	2	2	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1
Elutriate - Metals																												
# above EPA water quality criteria	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bioassay																												
>20% difference?		no		no						no										yes		no					no	
Significant difference?		no		no						no										yes		no					no	
Tissue																												
# significantly higher		1		0						0										0		2					1	

[1] Results exceed ERL (Effects range low) or ERM (Effects range medium) from Long et al. (1995).

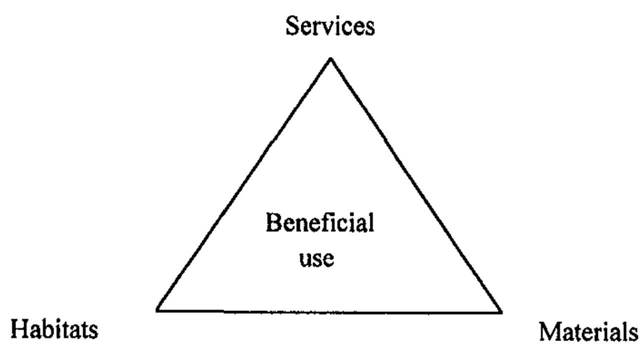
TABLE 3-3. CHARACTERISTICS OF EXISTING ODMDS SITES

Characteristic	Corpus Christi	Port Mansfield	Brazos Island
Final designation	1989	1990	1990
Final size	5,200 x 4,450 ft	5,200 x 3,000 ft	5,200 x 3,000 ft
Water depth	20 to 50 ft	20 to 50 ft	20 to 50 ft
Distance from shore	at least one mile	at least one mile	at least 1.25 miles
Dredging interval	18 months	15 months	13 months
Dredged amount	955,000 cy/yr	170,000 cy/yr	350,000 cy/yr
Sediment type			
Dredged material	sand	sand	sand
ODMDS bottom	98% find sands	sand	sand
Surrounding bottom	sandy mud	sand	sand

4. FORMULATION AND EVALUATION OF ALTERNATIVES

4.1 APPROACH TO DEVELOPMENT OF ALTERNATIVES

In theory, any type of dredged material could be considered for use in any Laguna Madre habitat to provide the services of protection, nourishment or creation. The following diagram illustrates that the array of beneficial use alternatives that is thus available for consideration is defined by combinations of material characteristics, habitat characteristics, and types of environmental services.



Our approach to the development of alternatives was to take an initial look at <u>all</u> possible combinations of services, habitats and materials. Through an iterative screening process, described in Section 4.2, we identified those combinations for which it seems most likely that: 1) a particular habitat has an environmental need, and; 2) dredged material has the potential to satisfy that need. This screening process eliminated the vast majority of theoretical combinations based on obvious problems (e.g., mud can't be used to build a sand beach) or based on the judgments of the study team as to what is likely to be most beneficial to the Laguna Madre ecosystem.

The evaluation of the alternatives is presented in Sections 4.3 (description), 4.4 (application of evaluation criteria), and 4.5 (evaluation of results). The one non-beneficial alternative considered, ODMDS disposal, is discussed in Section 4.6.

4.2 SCREENING OF ALTERNATIVES

The screening process involved taking a close and iterative look at the information presented in Sections 2 and 3 in order to identify (in our judgment) inappropriate, impractical, or unfavorable combinations of dredged material with environmental need or habitat conditions. The results are summarized below.

4.2.1 Environmental services and needs

As discussed in Section 1, consideration was given to three environmental services: habitat protection, habitat nourishment and habitat creation.

Protection. Wind and wave erosion are part of the natural dynamics of the Laguna Madre. Therefore, the simple fact that erosion occurs does not mean that a habitat needs the environmental service of protection. Using dredged material to provide the service of protection (as by building a protective berm, or otherwise using material to absorb erosive energy) was considered only for those habitats that are experiencing substantial net loss due to wave or wind erosion. Based on Section 2, habitat protection was judged as potentially being most beneficial in two settings:

- Lower Padre Island is experiencing net erosion because of factors which include a sand deficit, high longshore drift rates, and a thin barrier island sand body. Protection could be considered for areas that have the potential to experience breaching.

- Some dredged material islands that are relatively exposed to wind and wave action are experiencing a net loss of area. Protection could be considered for those islands where enough valuable habitat remains to justify saving.

At the reconnaissance scale of this study, protection alternatives were screened out for all habitats except those discussed above. Note that the nature of dredged materials, discussed in Section 4.2.3, was an important factor in further screening out alternatives to provide habitat protection.

Nourishment. For the Laguna Madre, no habitats were identified where the addition of dredged sediments would provide needed nutrients. Therefore alternatives for nourishment were considered to be limited to replacing eroded sediments in the same habitats which were identified above as potentially needing protection.

For South Padre Island, two specific habitats were judged as potentially having the greatest need for nourishment as a step in reducing net erosion rates: the gulf beaches, and fore-dune areas impacted by overwash. For dredged material islands, nourishment would be most appropriate for areas having the highest habitat value (Coste and Skoruppa, 1989).

<u>Creation</u>. In theory, many different types of habitat could be created in many different parts of the Laguna Madre. However, this use of material would be beneficial only if an environmental need were satisfied. Determining whether habitat creation would satisfy an environmental need is far from straightforward, for the reason that new habitat always comes at the expense of existing habitat. There are at least two ways to view this exchange of one habitat for another.

- On the one hand, it can be argued that creation of any new habitat provides certain environmental services and, unless the habitat in question is clearly in over-supply, the habitat thereby satisfies a "need". In this sense, any new habitat that will be used by fish and wildlife represents beneficial use, and there is no limit to the alternatives that can be formulated. If this concept of need were used, there would be no *a priori* basis for screening out alternatives.

- On the other hand, the habitat that is lost when the new habitat is created is clearly "needed" in the sense that it was developed as part of the natural system, and thus provides services which are intrinsic to the ecosystem. Artificial replacement habitats would seldom improve upon nature in an environmentally productive and diverse area such as the Laguna Madre. If this concept of need were used, there would be virtually no opportunities for beneficial use in the area, and the current study would have been unnecessary.

The issue of "need for new habitat" was resolved in a way that would allow some consideration of habitat creation as a beneficial use of dredged material, without allowing all such creation to be considered beneficial. Specifically, we identified two situations in which creating new habitat at the expense of existing habitat might be considered to fulfill a legitimate ecosystem need.

- The first category for potential habitat creation reflects the fact that the habitats of the Laguna Madre are dynamic: they grade from one to another, and the boundaries between habitats are nowhere fixed. Consequently, if nature might cause one habitat to expand at the expense of another, then the use of dredged material to <u>expand one habitat into another</u> has at least the possibility of being considered environmentally beneficial.

- The second category for potential habitat creation reflects the fact that there are certain habitats that already bear a strong human imprint. These include habitats such as dredged material islands created by humans, and perhaps seagrass beds degraded to the point of becoming unvegetated lagoon bottoms. Often such habitats are far less productive than natural ones, and may be less productive than they could be with improved management. Use of dredged material to <u>improve or expand these modified habitats</u>, even if at the expense of highly productive natural habitats, has the possibility of being considered beneficial if there is an overall net environmental gain when compared to non-beneficial placement. This second category of habitat creation is arguably the more beneficial in the Laguna Madre area. It reflects a concept that in a highly productive natural ecosystem, it is the disturbance caused by prior human activity that creates the main opportunities for beneficial use.

In short, habitat creation alternatives were considered only to the extent that they fit well with the natural dynamics of the existing ecosystem, or with the human modifications already made. All other possible alternatives for habitat creation were screened out without detailed evaluation.

As noted in Section 1, we have assumed that it will be possible to effectively design and build new habitats. Actual practice may be different. For example, it may be extremely difficult to place dredged material so that it would create the form, substrate, hydrology and other attributes of an algal flat or seagrass bed; or if that design is possible, to do so without having unanticipated effects on surrounding habitats. Similarly, it is recognized that building bird islands with muds would result in substrate characteristics in which eggs tend to stick or sink, thus reducing nesting success. We simply assume that such problems can be overcome by special measures, as by capping the fines with sufficient sand to support plants, nests and eggs, and to hold fines in place.

The practicality and effectiveness of such special design measures is not known, and the conclusions reached in this report should be conditioned accordingly. Reflecting the uncertainties about habitat design, many habitat creation alternatives would require small-scale demonstration before being implemented on a large scale.

4.2.2 Habitat constraints

Not every habitat listed in Table 2-2 is appropriately considered for beneficial use of dredged material. There are certain habitats in which the placement of dredged sediment is totally alien. For example, serpulid reefs represent a biogenic habitat that cannot be created or sustained by dredged materials. Therefore, alternatives involving this habitat need not be developed.

In addition, many of the persons contacted during the networking phase of this study would include algal flats and seagrass beds (and perhaps others) in any list of habitats in which placement activities cannot be tolerated. For the current study, algal flats and sea grass habitats were considered as available for conversion only in the context of expanding one natural habitat into another. Thus, for example, alternatives that would involve creation of bird islands are assumed to take place in areas of Laguna Madre where sea grasses are absent. (Note that, in practice, we were never able to identify any materials-services combination that would benefit algal flats.) All other habitats were considered as potentially expendable, in that their loss was not considered a certain and fatal obstacle to identification of alternatives. This approach was necessary in order to allow identification of more than a very small number of alternatives.

4.2.3 Constraints associated with texture of dredged material

The scope of this study did not allow for consideration of site-specific or reach-specific variations in dredged material characteristics. Instead, reflecting the information in Section 3 of this report, we classified the material as generally falling into one of two categories. Actual sample sites contain material that is a mixture of these two categories.

- The first category is predominately fine-grained material, i.e., muddy sediments that primarily contain silts and clays. This material, if disposed of without confinement, will flow away from the placement site quickly, or remain for a short time (weeks or months) until it is eroded and moved by waves, currents and/or wind. No permanent mound of material will be created. This is the material sometimes referred to as "soup", "fluid mud" or "fluff". Fluid muds can be used for nourishment only if applied throughout a habitat, as by spraying. They can be used for habitat creation only if confined, and if the habitat requires a mud substrate (or if appropriate substrate material is included in the habitat design).

- The second category is relatively coarse material, which in the Laguna Madre area is primarily a fine sand. Such material, if disposed of without confinement in relatively low-energy areas, will tend to remain in place, though there will be some erosion by waves or high winds. This material is sometimes referred to as "stackable" and has the potential to create permanent (or at least comparatively long-lived) habitat without the extra cost of containment levees. It also has the potential to provide the services of protection and (in sandy habitats) nourishment. Clays that are highly cohesive may behave somewhat like stackable sands with respect to formation of subaerial and subaquaous landforms, and may resist storm and wind erosion, but may act differently as habitat substrate.

In general, for dredged material to provide nourishment or serve as a platform for newly created habitat, it needs to be comparable in texture to the natural system. Therefore, alternatives which would use sand to create a mud habitat, or mud to create a natural sand habitat, are not considered. Most of the habitats listed in Table 2-2 have a substrate that includes significant amounts of fine sand. Therefore, there are more opportunities for using coarser material than fine material. One indicator of beneficial use potential was given by Coste and Skoruppa (1989), who indicated that materials with 70% or more sand are capable of supporting good bird habitat. During the sampling done as part of this study (LWA, 1998), this quality of sediment was found only in a few locations in the Upper Laguna Madre (see Table 3-1). Sediments containing 50% or more sand, which may provide marginal natural habitat, were found in the Upper Laguna Madre above LM4, and in the Lower Laguna Madre near the Arroyo Colorado and Port Isabel.

Table 3-1 indicates that 15 of 26 sites, or about 59% of the total dredged material, fall into the fluid mud category (<50% sand) and will thus be unsuited for many types of habitat creation unless special design measures are used. While we did not consider the use of muds in natural sand habitats, we did consider their use for artificial habitats (bird islands) on the assumption, explained previously, that special design measures would be practical and effective.

Nonetheless, the fundamental mismatch between the bulk of the material available and the material more suited for beneficial use represents a severe constraint to beneficial use planning in the Laguna Madre. For example, because of material texture, there is little potential for beneficial use alternatives that would provide the environmental service of protection (i.e., that would use sediments to build offshore berms, provide shoreline armor, or provide a protective mulch). The exception appears to be in the vicinity of the JFK Causeway (LM2), with 10% gravel. By and large, the material dredged from the Laguna Madre would not stay in place in the few high-energy erosive environments that occur in the area, except with the use of structures; and if structures are used, the dredged material would be redundant. The service of protection is not needed in low-energy environments.

If alternatives exist to use dredged materials for environmental protection in the Laguna Madre, they are likely to be very limited, e.g. to situations where coarse material is available near an eroding shoreline. Such alternatives would use little material, and the material used would be desirable for other purposes. We identified no such alternatives for consideration in this study.

4.2.4 Constraints associated with quality of dredged material

Alternatives were also screened out based on possible problems associated with the salt content of the water flux that would be associated with dredged material. This flux tends to be hypersaline. Only the lagoon and lagoon margin habitats are hypersaline. In other habitats, the natural water flux is less saline than lagoon water. The potential to use hypersaline dredged material to build or nourish such "fresher" habitats is assumed to be very limited, or in the alternative to require a mixing of the dredged material slurry with fresher water. As one example, along much of the Gulf of Mexico it has proven possible to beneficially use dredged material by creating salt marsh. The typical grasses of such marshes probably cannot tolerate the high salinity of the sediments dredged from the Laguna Madre, unless the material is mixed with fresher materials. Alternatives where there was a clear conflict between sediment salinity and habitat needs were not considered.

Alternatives were not screened out on the basis of dredged material toxicity. The characterization report prepared as part of this study (LWA, 1998; summarized in Section 3.4.1) identified possible concerns because of data points suggesting elevated levels of contaminants at certain dredging sites, and because in bioassays, the material reduced the survival of certain benthic organisms. There is no basis for concluding that the benthic effects were related to any cause other than fine texture. These data simply raise concerns that will need to be evaluated before large-scale beneficial use is practiced. For purposes of the current evaluation, the assumption is that beneficial use is not limited because of sediment contamination, but that material texture may be an important factor in determining suitable alternatives.

As indicated in Section 3.4.1, dredged material from the vicinity of sampling station BA-4 (North Floodway Outlet Channel) resulted in statistically significant reduction of survival of *A. abdita* in solid phase bioassay tests, compared to survival rates in Reference Control site material. This would indicate a potential to impact benthic organism survival due to placement of materials from the vicinity of sampling site BA-4. However, according to the Espey, Huston and Associates contaminant assessment (EHA, 1998), survival in REF2 (Brazos Island Harbor ODMDS) and all of the Lower Laguna Madre station materials was low for *A. abdita*. The difference between sampling station BA-4 survival and the average Reference Control survival was 20.5% versus a cutoff-value of 20%, and the difference between the tabulated and calculated t-values was small.

4.2.5 Results of screening process

Application of the process discussed above caused the vast majority of the theoretically available alternatives to be screened out. Only nine potentially viable combinations of dredged materials, habitats and environmental needs were identified and developed as alternatives. These alternatives are designated by the letters A, B, C, D, E, F, G, H, and I and are identified below.

Three alternatives were identified for using dredged material to nourish existing habitats. These involve the three habitats previously identified as having a potential need for nourishment, and are as follows.

A. Nourishing gulfside beaches
B. Nourishing washover areas
C. Nourishing dredged material islands

Note that in all cases the need for nourishment occurs in a high-energy environment, and if the material is to stay in place long enough to have value it probably needs to be taken from dredging reaches containing the coarser materials. As a practical matter, relatively few situations are likely to be encountered where fine sands are relatively close to areas which are experiencing high rates of erosion.

All remaining alternatives fit in the category of habitat creation. Many theoretical combinations of material-habitat-environmental need were screened out, such as those in which the dredged material would be mis-matched with the habitat substrate. The alternatives remaining fall into two categories, reflecting the two types of habitat creation opportunities discussed above.

Specifically, alternatives whereby dredged materials might be used to expand one natural habitat into another are as follows.

D. Extending tidal flats into submerged habitats
E. Extending seagrass beds onto naturally unvegetated lagoon bottoms

Alternative D would likely require coarser material; fluid muds (if confined) could be used for Alternative E.

Alternatives involving habitat that has already been modified are as follows.

F. Restoration of seagrass beds on degraded lagoon bottoms
G. Creating new dredged material islands with levee material from existing islands
H. Creating new dredged material islands using other confining material
I. Expanding existing dredged material islands

Alternatives F through I could use coarse material, but have been developed primarily with the intent of providing a potential use for fluid muds. As previously noted, there are no examples of using fine sediments to produce high-value, sustained habitat in the Laguna Madre system, and special design measures are assumed to be practical and effective in creating the indicated habitat. That assumption will require testing in demonstration projects.

Note that these nine alternatives were developed almost entirely from an environmental perspective. Factors such as economics and engineering technology were not considered. The nine concepts may not be the only beneficial uses that should be considered for the area; but we judge them to be among the most viable candidates that can be readily identified at this time. They offer at least some prospect of providing a meaningful environmental service in a sensitive ecosystem. Identification of these alternatives should not be taken as having any implications about whether any particular beneficial use is environmentally acceptable or advantageous.

At the time when this report was being initially drafted, a separate study was conducted regarding dredging placement alternatives (GBA, 1997). Several beneficial use alternatives identified by GBA are similar to those discussed above. One alternative identified by GBA, but not included here, would involve protection services (a submerged berm in the Gulf). GBA noted that the material texture made this option problematic; in our report, we used that factor to screen out the option. GBA also considered upland placement alternatives; that category of beneficial use was outside the scope of the current study.

The results of this study and of GBA (1997) are consistent in indicating that the limitations in beneficial use opportunities in the Laguna Madre reflect the realities of local conditions, and not the lack of imagination among those who have long been studying the area.

4.3 DESCRIPTION OF ALTERNATIVES

The first step in the evaluation of the nine alternatives identified in Section 4.2 was to develop short descriptions of each alternative. These descriptions begin with a brief explanation of how the alternative arose from the screening process. The descriptions then state the environmental service provided and habitat need fulfilled, and describe the type of material involved and the method by which the material would be used to accomplish the alternative. Measures that may be used to mitigate potential impacts, or to provide special design features, are noted as appropriate. Additional aspects of the alternatives are identified with respect to the evaluation criteria that are developed and applied in Section 4.4.

4.3.1 Alternative A: nourishing gulfside beaches

Screening process. Beach nourishment is a conventional beneficial use of dredged material (see Table 1-1) and readily emerged from the screening process as a logical combination of service-material-habitat.

Environmental service/need. Gulfside beaches along South Padre Island are eroding at rates ranging from 3 to 12 feet/year, and at 21 feet/year south of the Mansfield Pass jetties. The rapid erosion is attributed to a deficit of sand, high longshore drift rates, and a thin barrier island sand body. Dredged material of texture comparable to the beach sands could nourish the beach habitat in regions of rapid erosion, countering sediment loss and increasing the prospective life span of this habitat feature. The locations in greatest need of this service would be where island breaching is most likely to occur.

Material/method. This alternative would require course sediments, which are in relatively short supply in the Lower Laguna Madre (i.e., the areas of the GIWW nearest South Padre Island). Assuming transport by pipeline, long distance transport of material would be required across intervening habitats, including sensitive grass beds, as well as tidal and/or mud flats and dune habitats. Placement of material by jet spray probably would be utilized, as direct discharge of material from a pipeline would likely cause local erosion. Placement would be during periods of minimum bird and sea turtle usage. Because the habitat experiences a natural flux of sediment which is substantial, it is presumed that placement of new materials does not pose an unacceptable conflict between habitat and beneficial use. Elevated salinities are assumed to not be a problem because of the limited vegetation in the receiving area.

The alternative is conventional and should not require demonstration prior to implementation. However, the availability of sandy material within feasible transportation distance has not been evaluated. This is probably one of the most distant target habitats from the sediment source and, moreover, there is the possibility that even the coarser materials from the GIWW would be too fine to be well suited as beach materials. Thus, the feasibility of the alternative remains to be determined.

4.3.2 Alternative B: nourishing washover areas

Screening process. The service of nourishment was considered for all habitats. Washover areas represent one of the few habitats in the Laguna Madre ecosystem where nourishment might be a benefit.

Environmental service/need. Washover areas are channels cut by storm surges through the fore-island dunes at their lowest points. These features are generally perpendicular to the beach, and provide for transport of sediments to the back-island areas. Hurricane washover fan deposits are the primary source of sediments in the Laguna Madre (Briton and Morton, 1989). Washover channel sediments are generally sand and shell, with some deposition of mud. Inactive washover channels are often sites of temporary ponds that have thin algal mats around their edges, and commonly support mollusks.

Washover areas, especially on South Padre Island, are vulnerable to breaching during hurricanes. Breaching could allow for large-scale influx of Gulf water, which is less saline than lagoon water and thus could lead to freshening of the lagoon. Dredged material of appropriate particle-size composition could replenish (nourish) the areas where washovers now occur, thereby enhancing barrier island integrity and reducing the frequency and impacts of future washovers and island breaching. Under this concept, nourishment would not occur on washovers that are not at risk of breaching, on the premise that such features provide an important natural conduit for drainage of storm water.

Material/method. Materials and methods would generally be similar to those discussed for Alternative A (e.g. long-distance transport of coarse material, applied by spray, with placement during times of minimum bird occupancy). Because these habitats naturally experience extensive drainage and sediment movement, it is assumed that the placement of dredged material is not in irreconcilable conflict with existing habitat functions. It is assumed that if the sediment pore water were too saline to be compatible with the receiving habitat, some mixing of seawater would be used to dilute the salinity of the applied material. The practicality of this assumption has not been evaluated, and in general the alternative would require demonstration prior to large-scale implementation. The feasibility of long-distance sand transport also would need to be addressed.

4.3.3 Alternative C: nourishing dredged material islands

Screening process. This concept was the beneficial use alternative most often identified by persons contacted during the networking phase of our study, and readily emerged from the screening process as a logical combination of service-material-habitat.

Environmental service/need. Some dredged material islands are experiencing erosion. Maintenance of high-value island habitat could be sustained by providing a nourishing supply of sediment. An inventory of islands potentially needing sediment is provided in Coste and Skoruppa (1989) and includes areas in both the Upper and Lower Laguna Madre.

Material/method. The islands were built from the virgin material dredged from the GIWW, which was predominantly sand. Thus, nourishment would require coarse material as replacement substrate. Transportation distances could be lengthy if the limited supplies of coarse material are used far from their source, but at least some uses could be accomplished in comparatively close proximity to dredging locations. Locations for beneficial use very near to the dredging site are most likely to occur in the Upper Laguna Madre.

Placement of material would probably occur by jet spray (during times of minimum bird occupancy) and would be only within areas of existing habitat; it is this placement which distinguishes Alternative C from alternatives (such as I) which involve creating new habitat. This alternative would not require a demonstration project.

4.3.4 Alternative D: creating tidal flats

Screening process. This alternative was developed during the screening process in consideration of two factors: creation of new emergent habitat will generally require sands, as sands are the dominant substrate in the subaerial portions of the Laguna Madre ecosystem; and the sands are most likely to stay in place if the habitat being replaced is comparatively low-energy. The primary example where low-energy submerged areas adjoin emergent sand substrate is the lagoon margin, where tidal flats give way to seagrass beds.

Environmental service/need. This alternative would expand the lagoon-side areas of Padre Island into adjoining lagoon margins in order to create tidal flat habitat. Assuming that the habitat creation could be designed to mimic natural forms and processes (which is by no means a given), the result would be to increase the area of algal flats which are prime feeding areas for wading birds. Creation of tidal flats would likely be at the expense of seagrass beds, which provide very high-quality aquatic habitat. The potential exists that such placement of dredged materials on lagoon margins would be considered to have significant and possibly unacceptable impacts.

Material/method. The substrate characteristics of tidal flats would require course material, though fine material might be tolerated in greater concentrations than for the nourishment alternatives. Placement would be unconfined, probably by jet spray. Dilution of the salinity of the slurry might be required. This alternative would need to be demonstrated on a small scale before being considered for large-scale implementation.

4.3.5 Alternative E: creating seagrass beds on naturally unvegetated lagoon bottoms

Screening process. This alternative was developed during the screening process in consideration of two factors: creation of new submergent habitat can utilize fine materials; and the only readily envisioned way of changing submergent habitat is by changing its depth and thus its access to light. Unvegetated lagoon bottoms represent one of the few submergent habitats that arguably could be more productive.

Environmental service/need. Seagrass beds represent one of the most highly valued habitats in the Laguna Madre ecosystem. Alternative E would create platforms of shallow water suitable for seagrass colonization, by building up the elevation of unvegetated lagoon bottoms. It is assumed that vegetation of the platforms would occur naturally. Habitat values of the unvegetated lagoon bottoms (e.g. support of benthic macroinvertebrates, refugia during storms) would be lost. It remains to be determined whether this tradeoff of deep unvegetated to shallow vegetated habitat will be considered environmentally acceptable.

Material/method. Fine material would be placed in naturally deep areas, to bring the lagoon bottom up to a depth of 1.4 meters or less below the water surface. Sites selected would be outside of areas with strong circulation, and would be confined with underwater berms and caps constructed from coarser dredged sediment or using imported materials. The availability of such sites may be limited, since at least some of the deep unvegetated bottoms are believed to exist because of the existence of strong currents.

The alternative would need to be demonstrated on a small scale before being considered for large-scale implementation. A similar disposal concept was tested in September 1994 by the Galveston District COE, confining maintenance dredged material within submerged levees in the Lower Laguna Madre (Brown et al., 1997). Results from monitoring of the site are preliminary, but suggest that due to high turbidities associated with the dredged material, light penetration was inadequate to support seagrasses (Dunton, 1998). A demonstration program would need to evaluate the success of coarser-grained caps to minimize turbidity. An additional goal that has been recommended would be to undertake sediment pore-water studies to evaluate the extent of seagrass toxicity as measured by ammonia, sulfides, and total organic carbon (Dunton, 1998; Pulich, 1998).

4.3.6 Alternative F: restoration of seagrass beds on degraded lagoon bottoms

Screening process. This alternative was developed according to the same logic used for Alternative E, i.e., it may be possible to create high-value seagrass habitat by using dredged material to fill in lagoon bottoms, reduce depth, and increase light penetration at the bottom. Degraded lagoon bottoms were judged as a habitat for which modification could end up having net environmental benefits, especially since existing habitat could be considered to have diminished value compared to seagrass habitat.

Environmental service/need. This alternative would restore seagrass beds in areas where such beds were formerly located, thus restoring lost habitat and associated functions. The assumption is that habitat loss reflects light attenuation caused by brown tide and other sources of turbidity, and that light penetration can be restored by creating a very shallow water bottom. It is assumed that the modified water bottom could be designed to restore conditions necessary to support the flora, fauna and productivity of the original habitat.

Material/method. This alternative would be similar to Alternative E, in that fine material would be placed within confinement structures and capped with coarser materials. Differences with Alternative E are that locations would be in areas of former sea grass occurrence (and not unvegetated water bottoms), and the water bottom would be brought up to a depth of one meter or less below the water surface (shallower than for Alternative E, in order to overcome the effects of brown tide and other factors). This alternative would need to be demonstrated on a small scale, similar to Alternative E, before being considered for large-scale implementation.

4.3.7 Alternative G: creating new dredged material islands with levee material from existing islands

Screening process. Most of the existing bird islands in the Laguna Madre were created from dredged material. Not surprisingly, the use of dredged material to create emergent islands for bird habitat is the alternative that was most widely mentioned during the networking phase of this study. However, the existing dredged material is generally much finer than the virgin material that created the islands. Thus, we identified alternatives (G and H) which would provide the habitat using fine sediments.

Alternative G was developed in response to two further considerations: the existing islands contain coarse sediments and thus represent a potential source of confining material; and some existing islands could benefit from the mining of sediments. For example, some islands are classified as poor bird habitat because of predator access, and would benefit from a reduction in size of the island and proximity to the mainland (see for example, discussions in Coste and Skoruppa, 1989). To our knowledge, the notion of mining one island to create another island has not been identified in previous Laguna Madre studies.

Environmental service/need. Successful use of created islands by colonial birds for breeding, nesting, and foraging is high. For example, about 70% of colonial birds on the Atlantic coast use man-made islands for nesting (Batelle, 1997). While studies in the Laguna Madre are not comprehensive, island habitat is clearly of value (Coste and Skoruppa, 1989). To provide the best habitat, landforms would be shaped to provide optimum habitat value: land of low elevation with unvegetated tidal margins would be built for birds like plovers; and higher islands with shrubs and trees for pelicans. If necessary, sands would be used as a capping material to provide appropriate substrate and/or plantings would be used to establish appropriate vegetation.

Islands would be created at the expense of an existing aquatic habitat, and presumably the alternative would be limited to locations where such a habitat shift is judged environmentally acceptable. In particular, new islands would be built in lagoon areas that contain comparatively little seagrass. The information now available suggests this will be more likely to be possible in the Lower Laguna Madre than the Upper Laguna Madre. The mining of confining materials from existing islands would be done so as to enhance the habitat of those islands where practical.

Material/method. Except where stackable material is available, the islands would be built using fine-grained material. This material would be confined behind levees built by the mining of sands from existing islands. This concept, of mining the confinement material, is what distinguishes Alternative G from H. Mining would be done on existing bird islands that would benefit from such modification, and on islands where such mining could be tolerated. In the latter case, the mined sites would provide a location for placement of fluid muds. Thus, for example, island interiors could be scraped out to form levees, and dredged fines could be confined within the levees, thus limiting impacts to lagoon bottoms. Sites would be located in low-energy environments.

Extensive management activity could be required to establish and maintain appropriate habitat conditions, since the fine-grained material would be subject to erosion by wind, rain and storms, and also might tend not to support the vegetation favored by the target species. Thus, for example, it may be necessary to have an ongoing program to replace any eroded sands that were used to cap muds, in order to sustain successful nesting of some species of colonial birds. This alternative would need to be demonstrated on a small scale before being considered for large-scale implementation. The demonstration would need to include the concept of mining sediment from existing islands.

4.3.8 Alternative H: creating new dredged material islands with other confining material

Screening process. This alternative was developed in the same way as Alternative G, i.e., bird islands represent one of the few beneficial use opportunities in the Laguna Madre, but there is a need to build islands using fine material, which in turn means that confinement structures are needed. Alternative H assumes that the confined materials will come from sources other than existing islands.

Environmental service/need. This alternative is identical to G, except there would be no benefit from mining of existing islands to provide confining material. Indeed one intent of this alternative is to separate the effects of habitat creation accomplished by Alternative G, from the habitat modification (island mining) associated with that same alternative, and to indicate the potential for providing confinement in different ways.

Material/method. This alternative is identical to G, except that confining materials would be obtained from sources other than existing islands. Specifically, the confinement structures would be built using imported material, or through overdredging of the GIWW. Presumably, overdredged sites would then be used as the location for new islands, thus increasing the volume of fluid muds accommodated at a given location, and keeping impacts to lagoon bottoms to a minimum. Sites would be located in low-energy environments. Management requirements would be similar to Alternative G. Demonstration projects would be required, for the reason that (unlike existing islands) the habitat platform would be created primarily through the use of fine materials.

4.3.9 Alternative I: expanding existing dredged material islands

Screening process. This alternative was developed in the same manner as G and H. The distinguishing feature of Alternative I is that it would add land to existing islands, rather than create new ones.

Environmental service/need. This alternative would expand existing islands to create habitat suitable for nesting by colonial sea birds. Expansion could be to higher elevations (for pelicans), and/or laterally (for terns and plovers). The latter change would be at the expense of an existing aquatic habitat.

Material/method. Except in situations where stackable material is being dredged, the islands would be expanded using fine-grained material that would be confined behind levees. Levees could be built by dredging of existing islands (including the island being expanded), through overdredging of the GIWW, or with imported material. Sites would be located in low-energy environments. Islands with existing high-value rookery habitat would not be altered.

Under Alternative I, because a platform already exists upon which to place material, there would likely be less loss of additional bottom habitat for a given volume of disposed material than for Alternative G. Management requirements would be similar to Alternative G. At least one demonstration project would be required.

4.4 IDENTIFICATION AND APPLICATION OF EVALUATION CRITERIA

In accordance with the scope of this study, we performed a simplified environmental evaluation of the alternatives described in Section 4.3. The purpose of the evaluation was to identify at least some of the major factors that would need to be investigated if a given alternative were to be given serious consideration. The evaluation also provides insights as to which alternatives may be given the highest priority for the funding of demonstration projects. The evaluation is not intended to duplicate or constrain any aspect of the environmental impact analysis that will ultimately be done as part of the Dredged Material Management Plan.

The following evaluation criteria were identified as being of value in characterizing issues associated with the nine alternatives.

1. Benefits to natural habitats
2. Benefits to modified habitats
3. Direct impacts to existing natural habitats
4. Direct impacts to existing modified habitats
5. Impacts of material transportation
6. Turbidity impacts
7. Effects on water circulation
8. Potential resource conflicts
9. Limitations imposed by material type
10. Limitations on potential material usage
11. Risks of failure
12. Level of ongoing effort

For each criterion, each alternative was given a rating of 2, 1 or 0. A rating of 2 indicates that, among the nine alternatives considered, a given alternative raises greater concerns, has the potential to cause greater impacts, or arguably provides the fewest benefits. A rating of 0 indicates that, among the nine alternatives considered, a given alternative raises lesser concerns, has less potential to cause adverse impacts, or may provide greater benefits. A rating of 1 is intermediate. The ratings represent judgments by the study team and have not been reviewed by EPA or others; they are subject to revision. Even when finalized, the factors should be considered as only indicators of issues and concerns. The individual factors are not weighted or prioritized, and the ratings should not be added.

The discussions that follow briefly describe each criterion and the logic that was used to determine the ratings. The overall performance of the alternatives is summarized in Section 4.5.

4.4.1 Criterion 1: benefits to natural habitats

One objective of the beneficial use is to provide environmental services and needs to the habitats of the Laguna Madre. The extent to which different alternatives meet this objective is obviously a factor to be considered when the alternatives are evaluated. In many cases, the determination of habitat benefits is highly speculative, because most of the alternatives have yet to be demonstrated to be practical and effective. Thus the rating of alternatives with respect to habitat benefits is based on assumptions of success, and not demonstrated performance.

The rating of alternatives is relatively simple. Four alternatives (C, G, H, I) nourish or create habitats which are not native to the area, and thus are rated 2 (least benefits to natural habitat). Three alternatives (D, E, F) have as their purpose the creation of high value natural habitats and, presuming success, would provide the greatest benefits of this type; thus a rating of 0. The remaining alternatives (A, B), which nourish existing habitats, have intermediate benefits at a rating of 1.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
1. Benefit natural habitat	1	1	2	0	0	0	2	2	2

4.4.2 Criterion 2: benefits to modified habitats

This criterion is similar to Criterion 1, except the benefits considered are those to habitats that have previously been modified by human activity: dredged material islands and degraded lagoon bottoms. As previously noted, criteria have not been weighted. If weighting were used, consideration would be given to placing greater emphasis on Criterion 1 than Criterion 2.

Again the rating of alternatives is relatively simple. Four alternatives (A, B, D, E) have no effects whatsoever on modified habitats, and thus are rated 2 (least benefits to modified habitat). Three alternatives are given the best rating (0 in this case) because they address problems with existing modified habitats: Alternative C which would restore high-value islands now experiencing erosion; Alternative F, which would restore degraded lagoon bottoms to sea grass habitat; and Alternative G, which would improve existing dredged islands by selective mining of material. Alternatives H, and I get an intermediate rating because they provide new modified habitat, but without any benefits to existing habitat.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
2. Benefit modified habitat	2	2	0	2	2	0	0	1	1

4.4.3 Criterion 3: impacts to natural habitats

Most alternatives would place dredged material into an existing natural habitat. In some cases the existing habitat would be lost (replaced by a new habitat). In others, the presence of dredged material could have adverse effects on habitat function (e.g. through light attenuation). Since the natural habitats of the Laguna Madre ecosystem are generally very diverse and productive, this is a potentially severe adverse impact of dredged material disposal, whether beneficial or not. Indeed, based on the networking done as part of this study, at least some persons would weight this impact so that it would be the determining factor in beneficial use planning.

In consideration of this impact, alternatives that minimize or avoid effects on natural habitats would tend to be judged more favorably than those that would cause loss of prime habitat. The ratings are relative to the other alternatives, not to the habitat impacts of conventional non-beneficial disposal or ODMDS disposal. In all cases it is assumed that appropriate environmental management and mitigation measures would be successfully implemented (e.g. locating placement to avoid the highest-value habitats, and scheduling placement to avoid nesting periods).

The greatest impact (rating of 2) was assigned to the one concept that would deliberately cause the loss of high-value seagrass beds: Alternative D. The smallest impacts (rating of 0) were assigned to alternatives that put dredged material into habitats which have already been modified by human activity. These are Alternatives C (all material goes onto existing dredged islands) and F (all material goes onto degraded lagoon bottoms). This rating also was assigned to Alternative I, which would cause impacts only very near existing islands, and which thus raises fewer issues than those alternatives that build entirely new islands.

The intermediate rating (1) was assigned to all remaining alternatives. These would impact beach habitats (Alternative A), tidal flats (Alternative B), unvegetated lagoon bottoms (E), or unspecified habitats (but not seagrasses) near the GIWW (G, H). Higher ratings were not given for the following reasons:

- Alternatives A and B involve nourishment, rather than habitat replacement;
- habitat losses in Alternative E are presumed to be offset by creation of new seagrass areas;
- and for Alternatives G and H, impacted areas are assumed to be small and/or already partially disturbed by past dredging activity.

It is generally the case that the evaluations given here could be different in the context of site-specific and project-specific considerations. This is particularly true where 1 is the rating given alternatives, any of which could be viewed less favorably if they had greater effects on existing habitats than assumed here.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
3. Impact natural habitat	1	1	0	2	1	0	1	1	0

4.4.4 Criterion 4: impacts to modified habitats

This criterion is similar to Criterion 3, except the benefits considered are those to habitats that have previously been modified by human activity: dredged material islands and degraded lagoon bottoms. The principle consideration is that some of the existing dredged material islands provide habitat for nesting of colonial sea birds. Most persons contacted during the networking phase of our study expressed the concern that any beneficial use that places material on existing islands should not have significant adverse impacts on the bird habitat.

Five alternatives which have no relationship to islands at all (A, B, D, E, F) were assigned a rating of 0. Arguably, Alternative H, which creates new islands independent of existing islands, might be given the same rating. However, it is presumed that the increase in habitat of a given type will interact with the existing island habitats; hence this alternative is rated 1.

Alternatives C, G and I are given a rating of 2, to reflect the uncertain effects of placing material on existing islands (C, I), and of mining existing islands (G). It is presumed that such activities would be done in ways which minimize adverse effects (e.g. highest value habitats would be avoided; placement would not occur during nesting). Nonetheless, the rating is justified in light of the greater habitat modification, when compared to other concepts.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
4. Impact modified habitat	0	0	2	0	0	0	2	1	2

4.4.5 Criterion 5: impacts of material transportation

For this analysis it is assumed that material will be transported using conventional technologies, i.e., pipelines and booster pumps. It will be necessary to place the pipelines through existing habitats. For many alternatives, the pipelines will be placed through sea grass beds, and in some alternatives they will also be constructed across Padre Island habitats. Even if great care is taken in the construction phase of a project, substantial habitat disturbance can be expected to occur from pipeline placement and removal. If pipelines must be moved over time (in order to access different placement sites), impacts will be further increased. Impacts could be reduced (but not eliminated) if pipelines were left in place for reuse during repeated dredging cycles. The concept of transportation by barge transport and reslurrying of material at the placement site has not been assessed here.

Some Laguna Madre habitats that might benefit from dredged material are located near the GIWW, while others are relatively far away. Thus the distance over which material must be transported varies considerably among the alternatives. In general, adverse environmental impacts (along with dollar costs) will tend to increase with transportation distance. Longer pipelines also increase the potential for conflicts with navigation and recreational boating. With longer distances, the increased need for booster pumping will increase energy use, air emissions and noise.

Based on the location of the habitats benefited by different alternatives, the ratings are relatively straightforward. Habitats on Padre Island are the farthest from the GIWW, and they are separated from the GIWW by high-value seagrass beds and tidal flats. Moreover, sources of suitable material in the Lower Laguna Madre may not exist. Thus Alternatives A, and B, which would transport material to Padre Island, presumably would have the greatest impacts from material transportation. These alternatives are rated 2.

Dredged material islands would presumably be built relatively near to the locations of dredging or, if distances are great, the pipelines would tend to parallel the GIWW rather than transverse high-value lagoon habitat. Thus Alternatives C, G, H and I would likely have less impacts from material transportation and are rated 0. (As this example indicates, a rating of zero is not a rating of 'no impact'.) An intermediate transportation distance and habitat conflict is presumed for Alternatives D, E and F, which involve modification of submergent habitat within the lagoon; these options are rated 1.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
5. Material transportation	2	2	0	1	1	1	0	0	0

4.4.6 Criterion 6: turbidity impacts

A concern over existing dredging is that unconfined placement of fine materials causes turbidity impacts in the Laguna Madre and may adversely impact sea grasses and other habitats. The impact may occur during placement, or subsequently as the result of erosion. One purpose of considering beneficial use is to reduce this adverse impact. In general, the alternatives developed here would have less turbidity impacts than conventional disposal because they would: 1) use coarse materials which would settle out fairly quickly; 2) place material in emergent settings; and/or 3) confine fine materials.

Not all alternatives would be equally effective however. Thus ratings can be used to provide a relative comparison of turbidity impacts among alternatives. These ratings reflect the extent to which a given alternative involves one or more of the measures which would reduce impacts (coarse materials, emergent placement, confinement) and the anticipated effectiveness of those measures.

The greatest impacts (rating of 2) were presumed to occur from alternatives in which material would be placed in direct proximity to sensitive lagoon habitats. While impacts would be mitigated by placement methods (e.g. spraying) and/or confinement structures, they would be greater than for alternatives in which placement occurs in a less sensitive environment. Alternatives D, E and F were assigned this rating.

The smallest impacts (rating of 0) were presumed to occur from Alternatives G, H and I, as material would be confined and the location is near the GIWW. Alternatives G, H and I were assigned this rating. A rating of 0 also was given to Alternative A, as the placement location in gulfside beaches would not impact the Laguna Madre. The intermediate rating (1) was assigned to Alternatives B and C, where placement would be in or near the Laguna Madre and the material would not be confined.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
6. Turbidity impacts	0	1	1	2	2	2	0	0	0

4.4.7 Criterion 7: effects on water circulation

Any alternative that places dredged material within the Laguna Madre would cause changes to the bathymetry of the lagoon. In turn, the bathymetric changes would be expected to impact the natural water circulation of the Laguna Madre. In areas where the fill is regionally extensive (i.e., lagoon bottoms are raised or filled in), the volumetric flux of circulation would be reduced and wave patterns could be altered. In areas where fill is localized (e.g. new islands), effects would be to provide localized modifications to currents and waves.

The effects of such circulation changes cannot be assessed without site-specific information and may not always prove to be adverse. Thus, ratings for Criterion 5 reflect the fact that circulation impacts are a concern, and not necessarily the net severity or acceptability of the effects. Note that areas impacted by dredge fill also are likely to be less accessible to boats; thus this issue stands as a surrogate for certain impacts to recreational fishing.

For purposes of this general assessment, the greatest impact (rating of 2) was assigned to Alternatives E and F, as these would purposely raise the lagoon bottom over a relatively large area in order to create shallow platforms for seagrass beds. Alternative D also was rated 2, as emergent land would be created in areas that are now submerged. For all these alternatives, the scale of the impact would be much greater than for other concepts.

An intermediate rating (1) was given to those alternatives (G, H and I) that would create or expand dredged islands in currently submerged areas. Note that the descriptions of these alternatives indicated an intent that islands would be sited in low-energy areas, which means that the effects would not occur in areas where circulation is most vigorous. A rating of 0 was given to Alternatives A, B and C, as all placement would be on emergent land.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
7. Water circulation	0	0	0	2	2	2	1	1	1

4.4.8 Criterion 8: potential resource conflicts

Many environmental resources, other than habitat, are potentially impacted by beneficial or non-beneficial disposal of dredged material. Following are a few examples of such issues in the Laguna Madre.

- burial of cultural resources (e.g. shipwrecks) by dredge fill;
- creation (or loss) of land which can be used for coastal cabins;
- changing the value and attractiveness of the area for recreational visitors;
- because of the above, changing the stresses on protected species.

Issues of this type can generally be characterized as involving impacts to or conflicts with various non-habitat resources. More so than other impacts discussed here, resource conflicts tend to be site- and project-specific. Thus, in terms of resource conflicts it is possible to evaluate the conceptual alternatives of this study only in the most general way. The approach we have taken is to rate alternatives based on their probable scale and type, on the assumption that greater potential impacts are likely from those alternatives which would alter the largest amounts of area, would bury stable substrate, or would change the land-water pattern.

For purposes of this general assessment, the greatest impact (rating of 2) was assigned to Alternatives D, E and F because of their potential for burial of lagoon bottom substrate over a large area. An intermediate rating (1) was given to those alternatives that would create small islands in currently submerged areas: Alternatives G, H and I.

A rating of 0 was given to Alternatives A, B and C as they involve nourishment and are intended to mimic natural sedimentation processes. Thus, if done in ways that avoid key resources (e.g. known shipwrecks, turtle nests, human swimming areas, algal flats, colonial bird nests, coastal cabins), resource conflicts should be minimized. Note that the habitats associated with these alternatives are among the most dynamic in the ecosystem; this is a further indication of the potential to minimize the effects of beneficial use.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
8. Resource conflicts	0	0	0	2	2	2	1	1	1

Note that the ratings for Criterion 8 are the same as for Criterion 7 but for different reasons.

4.4.9 Criterion 9: limitations imposed by material type

In the networking done for this study, one of the most common observations was that beneficial use of sands is much more practical than beneficial use of silts and clays. The sands are more compatible with common habitat substrates and habitat requirements (e.g. for bird nests) and they can be used in low-energy environments without the expense of confinement structures. The fine materials require confinement to stay in place, and the texture is not well suited to emergent habitats because the substrate would be of low value and/or the material would be lost to wind erosion.

Criterion 9 reflects this problem of material type. Alternatives that would utilize dredged sediments in ways that depart from the existing environment are judged as posing greater concerns than alternatives that provide a good match between material type and habitat substrate.

For purposes of this general assessment, those options that apply coarse material to habitats with a sandy substrate are rated 0, indicating the greatest compatibility of material type: Alternatives A, B, C and D.

Alternatives E and F would use fine material in habitats where fine substrate is common. A rating of 1 was assigned because the alternatives are unconventional.

Alternatives G through I were designed for the specific purpose of providing a use for fluid muds (in confined situations), on the assumption that with careful design and intensive management, substrate compatibility problems can be overcome. However, until the ability to provide such design and management is demonstrated, it is appropriate to assign a rating of 2 to these alternatives.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
9. Material type	0	0	0	0	1	1	2	2	2

4.4.10 Criterion 10: limitations on potential material usage

As discussed at various points in this paper, the conventional alternatives for beneficial use require coarse sediments; there are essentially no proven uses for fine materials. One result of this fact is that in this study we have emphasized the development of conceptual alternatives that might be able to beneficially use fluid muds. Other evaluation criteria downgrade such alternatives for reasons such as substrate incompatibility

(Criterion 9) and risk of failure (Criterion 11). It is appropriate that the evaluation also indicate potential advantages of such alternatives, in that they could potentially utilize the materials that are most commonly dredged in the area. Another way of looking at Criterion 10 is that alternatives that use coarse material are less favored, because they could accommodate only a small fraction of the total dredged sediment supply.

The application of this criterion does not imply, one way or another, whether all dredged materials could be beneficially used, or if so, whether full use of materials (and consequent loss of existing habitats) is environmentally desirable. Indeed, our judgment is that beneficial use opportunities are sufficiently limited in the Laguna Madre so that dredging will always lead to extensive non-beneficial disposal (locally, or outside the area). However, it should be noted that alternatives that do provide for beneficial use of fine material through confinement do at least offer the prospect of reducing washback of sediments into the GIWW and thus may reduce the long-term need for GIWW dredging.

For purposes of this general assessment, a rating of 2 was assigned to those alternatives that use only coarse materials and only to nourish existing habitats (Alternatives A, B and C). Such uses would provide uses for relatively small quantities of material. Therefore their implementation would provided a limited solution to the problem of dredge disposal.

The greatest potential for overcoming limitations in the ability to beneficially use dredged material (rating of 0) may lie with Alternatives D, E and F because of their potential to create habitat over large areas, and because the habitat created is relatively compatible with fine-grained material and is presumably highly productive. In effect, this is an advantage of large-scale activity, whereas Criterion 6 reflected disadvantages of scale.

Alternatives involving creation or expansion of islands are given an intermediate rating (1): Alternatives G, H and I. Even if these options prove viable, it is not certain that they could utilize the full supply of available material; or if such full-scale use (and loss of existing lagoon habitats) would be environmentally acceptable.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
10. Material usage	2	2	2	0	0	0	1	1	1

4.4.11 Criterion 11: risks of failure

Currently available materials limit the potential for conventional uses such as beach nourishment or bird islands. One result is that in this study we have identified a number of non-conventional alternatives. While some of these alternatives offer intriguing possibilities, they are not demonstrated and known to be practical and effective. Therefore, implementation would be experimental and there would be a risk (perhaps substantial) that beneficial objectives would not be fully met.

Demonstration projects are a necessary step in the further evaluation of these experimental alternatives. Pending such demonstration, it is appropriate to use our current understanding of risks to compare the alternatives in terms of their potential for failure.

For purposes of this general assessment, the greatest impact (rating of 2) was assigned to Alternatives G, H and I, which would attempt to use fine material to create dredged island habitats that normally require coarse material. Creation of seagrass habitat in Alternatives E and F is experimental and limited experience has shown a high risk of failure due to turbidity; those alternatives were rated 2. Alternative D also was rated 2 because, to our knowledge, the use of dredged material for tidal flat creation has not previously been attempted.

The issue of risk is of least concern (rating of 0) for Alternatives A and C, which are conventional. Precedents for Alternative B do not exist in the area, but the concept (island nourishment) does not require any unusual actions; an intermediate rating (1) was given to this alternative.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
11. Risks of failure	0	1	0	2	2	2	2	2	2

4.4.12 Criterion 12: management requirements

The descriptions of certain alternatives (e.g. those involving use of fine material on dredged islands) noted the potential that beneficial use might not simply result from placement of material, but could require ongoing management activities so that desired habitat conditions would actually develop. Requirements for ongoing management would add to costs and uncertainties and, depending on the type of management needed, could also cause additional impacts (e.g. consumption of fertilizers). Thus, it is appropriate for the evaluation to identify those alternatives for which management requirements are potentially greatest.

For purposes of this general assessment, a rating of 2 was assigned to Alternatives G, H and I, on the expectation that management issues would be greatest for beneficial uses which involve placing fine material in an emergent setting. Management could include landscape reshaping, capping of muds with sand substrate, vegetative plantings, and other measures.

An intermediate rating (1) was given to the other alternatives which would create new habitats (D-F), on the assumption that these alternatives could require some reshaping of material and/or intervention to create conditions favorable for vegetation growth. A rating of zero was given to the nourishment alternatives (A-C), on the assumption that the placement of material would result in beneficial use without any need for further management actions.

In summary:

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
12. Management	0	0	0	1	1	1	2	2	2

4.5 SUMMARY EVALUATION OF BENEFICIAL USE ALTERNATIVES

The following matrix summarizes the evaluations presented in Section 4.4.

Factor	A: Nourish beaches	B: Nourish washovers	C: Nourish islands	D: Create tidal flats	E: Create seagrass	F: Restore seagrass	G: Mine & build islands	H: Build islands	I: Expand islands
1. Benefit natural habitat	1	1	2	0	0	0	2	2	2
2. Benefit modified habitat	2	2	0	2	2	0	0	1	1
3. Impact natural habitat	1	1	0	2	1	0	1	1	0
4. Impact modified habitat	0	0	2	0	0	0	2	1	2
5. Material transportation	2	2	0	1	1	1	0	0	0
6. Turbidity impacts	0	1	1	2	2	2	0	0	0
7. Water circulation	0	0	0	2	2	2	1	1	1
8. Resource conflicts	0	0	0	2	2	2	1	1	1
9. Material type	0	0	0	0	1	1	2	2	2
10. Material usage	2	2	2	0	0	0	1	1	1
11. Risks of failure	0	1	0	2	1	1	2	2	2
12. Management	0	0	0	1	1	1	2	2	2

Below, these evaluations are interpreted to get an overall sense of the prospects and priorities for beneficial use of Laguna Madre dredged material.

4.5.1 Alternative A: nourishing gulfside beaches

This alternative is a conventional beneficial use of dredged materials that would be expected to pose fewer environmental concerns than most other alternatives discussed here. However, in the specific context of the Laguna Madre, this alternative faces a severe logistical problem in which appropriate dredged materials, if available at all, are located very far from potential use areas (Criterion 5). Therefore, transportation impacts (and costs) could be significant. Moreover, the relatively fine nature of the available sands may not be suitable for nourishment of the high energy beach environment and, even if this does not prove to be the case, relatively little material would be beneficially used (Criterion 10).

Any detailed assessment of this alternative could determine that it is simply impractical, infeasible or not cost-effective. If the alternative were implemented, it would provide for beneficial use of relatively little material and that material (sands) could probably be beneficially used in other, more cost-effective ways. For these reasons, Alternative A appears to be of limited importance to long-term planning for beneficial use of Laguna Madre sediments.

4.5.2 Alternative B: nourishing washover areas

Alternative B poses many of the same issues as Alternative A, in that it faces significant logistical obstacles and, even if implemented, would provide a use for relatively little material that might more readily be used elsewhere. An added concern is that this is not a conventional alternative: there is some risk that nourishment would not produce net benefits, especially if materials could not be placed in ways that would avoid impacts on existing algal flats.

However, if the alternative did in fact accomplish the objective of reducing storm breaches on South Padre Island, the resulting benefits could arguably be more significant than almost any of the other beneficial uses considered here. None of the evaluation criterion effectively capture this benefit, which relates to secondary impacts of maintaining island integrity. Because of the potential benefit, it would be appropriate to consider a prototype site-specific evaluation of the alternative. The elements of such an evaluation would include the following.

- the dynamics of the prototype washover area would be studied in sufficient detail to determine the potential contribution of nourishing sediment;
- the appropriate substrate texture would be determined;
- locations of potentially usable dredged materials would be determined;
- impacts of material transport would be assessed in site-specific terms;
- existing habitats of the area would be assessed, to determine potential impacts from material placement;
- alternative placement methods would be assessed to determine probable impacts of placement; and

- the potential for actual island breaching, and the benefits of preventing that breaching, would be assessed.

The evaluation also could generate initial estimates of cost and cost-effectiveness. The results of the evaluation could be used to design a demonstration project. The project probably would be very small and would transport material by shallow-draft barge rather than a pipeline.

4.5.3 Alternative C: nourishing dredged material islands

Alternative C is among the most conventional of the concepts discussed here. Assuming that the alternative can be implemented in ways that minimize effects on existing high-value habitats, the alternative would provide beneficial use for a modest amount of dredged material, and would probably be more cost-effective than any other option. The primary limitation of the alternative is that it does not provide for use of the fluid muds which make up the bulk of the material dredged from the Laguna Madre (see Criterion 10). This limitation does not constrain implementation of Alternative C, but rather is a reason why we have given a close look at other alternatives that would use finer materials.

An appropriate step in further development of this alternative would be to expand and update the inventory of islands presented in Coste and Skoruppa (1989), with the specific objective of identifying islands where nourishment is both needed, and can be done without unacceptable adverse effects on existing habitat. Locations of potentially suitable material would then be identified, and it would be possible to provide further assessment of issues such as transport impacts, as well as to develop preliminary cost estimates.

4.5.4 Alternative D: creating tidal flats

Among all combinations of environmental need, habitat type and material characteristics, Alternative D was the only one in which there was a plausible prospect of creating natural emergent habitat. However, in practice, this approach raises many concerns, as indicated by the numerous ratings of 2 on the matrix. Probably the greatest concern is that this use would occur at the expense of productive lagoon bottoms, and thus probably would involve the loss of seagrass habitat (Criterion 1). Also, because the concept would be experimental, there is no assurance that the newly created habitat would be highly productive, or that habitat benefits gained would be greater than those for the lost habitat.

In our judgment, while this alternative is theoretically available to the Dredged Material Management Plan, the potential adverse effects on existing habitat would almost certainly cause it to be rejected unless the lagoon habitat which is being replaced were determined to have a low value. It may be useful to study the Laguna Madre more closely to identify possible locations where this alternative might be implemented, or at least studied in a demonstration project. However, it also could be appropriate to simply drop Alternative D from further consideration.

4.5.5 Alternative E: creating seagrass beds on naturally unvegetated lagoon bottoms

Alternative E would use dredged material (confined where necessary) to build submerged platforms on the lagoon bottoms. The reduced water depth is expected to increase light penetration to the newly raised bottoms, thus promoting growth of sea grasses. The alternative is conceptually attractive in that it could provide for use of a comparatively large volume of fluid muds, and it could result in restoration of a habitat that is extremely important to the existing ecosystem. The potential for this alternative is greatest in the northern part of the Lower Laguna Madre (Figure 2-5) where sediment size is relatively fine (Table 3-1).

The evaluation of Alternative E presented in Section 4.4 indicates concerns about the practical ability of implementing this alternative (i.e., whether sea grass habitat can actually be built; Criterion 11), and about some of its impacts (e.g. to macrobenthos, water circulation, cultural resources; Criteria 6-8). A demonstration project may be appropriate to evaluate these concerns in a site-specific context. It is arguable that Alternative F, which resembles Alternative E in most respects, is a preferred approach because the new habitat would be built on degraded lagoon bottoms rather than (for Alternative E) undisturbed but unvegetated bottoms. If so, then a demonstration project for Alternative F might take priority over one for Alternative E.

4.5.6 Alternative F: restoration of seagrass beds on degraded lagoon bottoms

Alternative F is identical to E except that F involves building seagrass habitat on degraded lagoon bottoms rather than natural but unvegetated bottoms. Like Alternative E, this approach is conceptually attractive in that it could provide for use of fluid muds, and it could result in restoration of a habitat that is extremely important to the existing ecosystem. It is arguably better than E because the habitat that would be lost is a low-energy and degraded lagoon bottom (see Criterion 2). This indicates that habitat losses would be less than for Alternative E, and also that the confining structures and confined material might be more likely to stay in place. However, as was the case for Alternative E, the information presented in Section 4.4 indicates concerns about the practical ability of implementing Alternative F and about some of its impacts.

A demonstration project may be appropriate to evaluate these concerns in a site-specific context. Demonstration of Alternative F could take priority over Alternative E, because (for reasons given above) F appears to be a potentially better concept and because such a project could also serve to demonstrate most aspects of Alternative E. Prior to undertaking a demonstration project, it would be useful to evaluate monitoring results of the experiment conducted in 1994 by the Corps of Engineers (Brown et al., 1997). It also would be useful to study lagoon bottoms that reportedly contain degraded habitats, to better understand the history and needs of these habitats.

One objective of the demonstration would be to determine if it is possible to modify water bottoms in ways that restore conditions necessary to support the flora, fauna and productivity of the original sea grass habitat. Another objective would be to determine the effectiveness of submerged confinement structures and caps in *preventing erosion and material wash back to the GIWW. A demonstration also could provide limited site-*specific insights on issues such as impacts to water circulation, and provide data for assessment of sediment pore-water, to evaluate the extent of seagrass toxicity from ammonia, sulfides, and total organic carbon.

4.5.7 Alternative G: creating new dredged material islands with levee material from existing islands

Alternative G was developed as a means of addressing several concerns that were raised during the networking phase of this study. It provides for use of the dominant dredged material -- fluid muds, for a habitat of recognized value -- bird islands, and does so primarily in areas already partially disturbed by dredging -- near the GIWW. The alternative recognizes that confining material will be needed to implement this concept (and possibly to provide a surficial cap to produce better habitat), and that some existing islands are not ideal habitat because they are too continuous or insufficiently isolated from predators. The approach deals with both these factors by proposing to obtain the confining and capping material by mining existing islands. The resulting improvements to existing islands would add to the benefits of new islands to produce a potentially useful overall result. (The phrase 'fixing two bird islands with one dredge comes to mind.)

The evaluation presented in Section 4.4 identifies many concerns over this alternative, not least being the impacts to existing lagoon bottoms and water circulation, and the high risk of failure which results from the use of fine material (Criteria 3, 7, 9, 11). This suggests that it would be useful to undertake a demonstration project to determine if the concept is feasible, and to better identify benefits and impacts in a site-specific context.

Several activities could be undertaken prior to project demonstration. One would be to update and expand the inventory of existing islands done by Coste and Skoruppa (1989), in order to identify islands where sediment mining could be beneficial. Another would be to carefully describe the form and substrate of bird island habitat in order to develop the design specifications for a project. A third would be to assess lagoon bottom conditions in order to identify potential areas where this type of alternative could be implemented with comparatively less effect on existing high-value habitats.

4.5.8 Alternative H: creating new dredged material islands with other confining material

Alternative H differs from G only in the source of confining material. For Alternative H, material could come from overdredging of the GIWW (with the over-dredged areas then used for new islands) or through imported materials (rock, geotubes, etc.). One key issue for both Alternatives G and H is whether it will prove possible to use fine material to build effective bird island habitat (Criterion 9). Almost certainly the answer is no, if the material is simply placed within confinement levees. Thus the need to is to develop special designs which have the potential to use large amounts of fine material, while still providing a substrate suitable for containing nests and eggs. Presumably, the approach to a demonstration project for Alternative G would provide a foundation for further assessment of Alternative H as well. Independent assessment of Alternative H is arguably premature until such a demonstration has been accomplished.

4.5.9 Alternative I: expanding existing dredged material islands

Alternative I differs from H in that the location of material placement would be on existing islands, to build them higher (for pelicans) or outward (for plovers). Thus effects on existing submerged natural habitats would be expected to be less (Criterion 3). As with Alternatives G and H, a key issue is whether it will prove possible to use fine material to build effective bird island habitat (Criterion 9). Presumably this question will be addressed through the demonstration project discussed under Alternative G. Independent assessment of Alternative I is arguably premature until such a demonstration has been accomplished.

4.6 PLACEMENT AT AN EXISTING ODMDS

One non-beneficial placement alternative was within the scope of this study: placement into one of the three existing ODMDS locations described in Section 3.5. These sites have been designated only for placement of sediments dredged from the major navigation channels which are inland from them, and are not now designated for placement of GIWW dredged material. Any discharge of dredged materials from the GIWW at a given site could not occur unless and until that site had been redesignated. The redesignation would follow specified regulatory procedures, including an environmental impact analysis.

The assessment of this option has been done at a screening level, which provides for an initial assessment of whether ocean-dumping criteria may be satisfied. This does not represent the detailed analysis required before an actual placement activity is approved.

For this study, the one redesignation issue considered is whether the materials dredged from the GIWW are suitable for placement at the ODMDS sites, in accordance with the ocean dumping regulations at CFR 227.13. A first review under these regulations is to determine if the material proposed for placement in the ocean is substantially the same as the substrate of the proposed placement site. This condition is not met in the Laguna Madre. All three ODMDS sites are characterized by a predominantly sandy substrate, whereas the bulk of the dredged material from the GIWW is fine-grained (compare Tables 3-1 and 3-2).

Because the initial screening criteria were not met, a second review was required under the regulations to determine if the discharge of the material would cause exceedances of water-quality criteria, toxicity to organisms, or excessive bioaccumulation. One step in such a review is provided in the Characterization of Dredged Materials report prepared as part of this Work Assignment (LWA, 1998). The characterization report found that few significant exceedances, toxicities or bioaccumulations were observed (refer to discussion at Section 3.4.1). Impacts to survival of certain benthic organisms occurred in both uncontaminated reference and test sediments in comparison to clean sands used as true controls, and appear to be caused by the texture of the material.

However, given the evaluations presented in this document and in the characterization report, there are certain reaches of the GIWW where some concerns exist, while in other areas there is no significant concern. Geographic areas of concern are in the vicinity of Baffin Bay and south toward the Land Cut, and in the vicinity of the North Floodway Outlet Channel. The former area exhibited elevated levels of metals in sediment, water and elutriate, but few exceedances of criteria other than copper. Copper commonly exceeds EPA marine water quality criteria in the area, though the data are suspect. For material from the latter area, toxicity tests resulted in significant impacts. The metals levels and toxicity impacts are discussed in more detail in Section 3.4.1.

For those areas where there is no concern, there is no reason to believe that there will be adverse impacts to the water column or benthos as a result of ocean disposal of dredged materials, given the results and conclusions of the sediment and water analyses required by the regulations. The only limiting factors would be cost analysis of the offshore disposal (transportation) and logistics of dredging, for which the Corps of Engineers is responsible.

For those areas of concern along the GIWW, (e.g. metal exceedances in water and elutriate), the material would require further testing before a decision could be made for offshore disposal (i.e. more extensive sampling of sediments). The failure of the toxicity analysis for *Ampelisca abdita* to meet the required criteria in sample site BA-4 sediment indicated that material removed from that reach would not be suitable for disposal at the offshore sites.

5. SUMMARY AND RECOMMENDATIONS

Study approach. In this study we have considered how material dredged from the GIWW of the Laguna Madre, Texas, might provide the environmental services of habitat nourishment, habitat protection, or habitat creation to the Laguna Madre ecosystem. Refer to Section 1 for an explanation of this approach.

As a predicate to the development of conceptual beneficial use alternatives, we summarized the literature on the environment of the Laguna Madre ecosystem. This summary, presented in Section 2, includes a consideration of physiography, climate and hydrology, and habitat characteristics for the barrier island system, the lagoon itself (including highly valued seagrass beds), and islands formed from the material dredged when the GIWW was first constructed. We considered the results of studies on environmental changes that have occurred to the ecosystem, including a reduction in salinity, changes in barrier island integrity, the occurrence of brown tide, and changes to seagrass habitat.

As a second predicate to the development of alternatives, we summarized historic dredging and placement practices in the Laguna Madre, what is known about the impacts of these practices, and the nature of the material that is likely to be available from future dredging. This review, which is summarized in Section 3, also considered conditions at three ocean dumping (ODMDS) sites formally designated by EPA.

Based on the habitat needs of the system, and the material potentially available, we identified nine conceptual alternatives that might accomplish some degree of beneficial use of GIWW dredged material in the Laguna Madre ecosystem. The screening process that led to identification of the alternatives is provided in Section 4, along with a brief description of each concept. The alternatives are:

A. Nourishing gulfside beaches
B. Nourishing washover areas
C. Nourishing dredged material islands
D. Extending tidal flats into submerged habitats
E. Extending seagrass beds onto naturally unvegetated lagoon bottoms
F. Restoration of seagrass beds on degraded lagoon bottoms
G. Creating new dredged material islands with levee material from existing islands
H. Creating new dredged material islands using other confining material
I. Expanding existing dredged material islands

Constraints on beneficial use. In Section 4 we also evaluated the nine alternatives in terms of twelve criteria:

1. Benefits to natural habitats
2. Benefits to modified habitats

3. Direct impacts to existing natural habitats
4. Direct impacts to existing modified habitats
5. Impacts of material transportation
6. Turbidity impacts
7. Effects on water circulation
8. Potential resource conflicts
9. Limitations imposed by material type
10. Limitations on potential material usage
11. Risks of failure
12. Level of ongoing effort

The evaluations were generalized and did not consider the many site-specific and project-specific factors that would be necessary to determine if a particular beneficial use is environmentally acceptable and cost-effective. However, the results of the evaluations make it clear that beneficial use in the Laguna Madre is especially constrained by two factors: habitat conditions and material type.

- <u>Habitat conditions</u>. Because the Laguna Madre is a highly productive natural ecosystem, there are comparatively few habitats that are in need of environmental services that might be provided by dredged material. On the contrary, for the higher valued habitats, the placement of material would likely have adverse effects greater than probable benefits. Habitat impacts from alternatives involving long-distance pipeline transport are also a concern. Reflecting this constraint, one emphasis of this report was to develop alternatives that involve enhancement of those habitats that had previously been modified, rather than natural habitats.

- <u>Material type</u>. The dominantly fine-grained material that is most commonly dredged from the GIWW is not well suited to conventional beneficial uses such as beach nourishment or creation of bird islands. Use of this material will require confinement, innovative designs for creation of new habitats, and demonstration projects.

Although we were directed not to make economic determinations in this study, common sense makes it obvious that beneficial use alternatives will tend to be costly, because of the need for long-distance transportation, impact mitigation, confinement and/or innovative design.

<u>Cost-effectiveness implications</u>. Our work assignment directed us to look only at beneficial use options (and ODMDS placement), and not at conventional non-beneficial placement. However, the conclusion on cost made above means that most types of beneficial use can be expected to be substantially more expensive than the conventional practice. And our experience makes it clear that federal policy is interpreted by the USACE to require the use of the lowest cost, environmentally acceptable placement practice.

Consequently, so long as conventional placement is judged to be environmentally acceptable (or, acceptable with appropriate mitigation measures), it is not realistic to expect that there can be large-scale beneficial use of sediments dredged from the GIWW in the Laguna Madre. If beneficial use does occur at a significant scale, it will be because conventional placement has been rejected, or substantial subsidies have been found.

Most cost-effective beneficial use alternative. In our judgment, Alternative C (nourishment of existing dredged material islands with sands) is the only beneficial use alternative that may be cost-effective when compared to conventional placement. This cost-effectiveness advantage would likely occur only where the dredged material is at least 70% fine sand and where there are nearby islands in need of nourishment, hence no need for long-distant transport. As a step toward implementing such beneficial use, the next logical action would be to closely inventory the existing islands of the Laguna Madre in order to identify habitat conditions and potential sediment needs, as well as settings in which habitat values are so high as to preclude material placement. This inventory would expand upon the previous study of Coste and Skoruppa (1989) and ideally it would be integrated with the inventory discussed below regarding Alternative G.

Need for further consideration of beneficial use alternatives. The fact that beneficial use is likely to be costly does not mean that there is no need for further evaluations. On the contrary, the key decision identified above -- whether existing practices are determined to be environmental acceptable -- may be reached by a comparison of conventional placement to other alternatives. Thus, it will be appropriate to gain additional insights on offshore (ODMDS) placement, and at least some beneficial use options.

Assessment of ODMDS placement. If ODMDS placement is to be compared to conventional placement, then information will be needed regarding the environmental consequences of putting fluid muds into the high-energy, sand bottom habitats of the three existing ODMDS sites. Possible concerns over sediment chemistry, identified in the separate characterization report (LWA, 1998), also should be addressed. And, it would be of value to determine if bottoms containing finer materials are available nearby, and to evaluate the potential for ODMDS designation of additional sites. A small-scale pilot study could be conducted to provide field verification of effects such as turbidity and bottom smothering.

Assessment of beneficial use alternatives. Beneficial use evaluations need to extend beyond Alternative C, discussed above. Based on the assessment summarized in Section 4.5, we recommend that EPA and ICT consider taking a closer look at three alternatives.

- Alternative B (nourishing washover areas) is of interest because it offers the potential for significant environmental benefits from a reduced risk of island breaching. The elements of a more in-depth evaluation of Alternative B are listed in Section 4.5.3, and include studies of potential receiving areas, substrate needs, impacts from placement, and impacts from long-distance transport. In effect, the additional effort involves a reality check on the alternative.

- Alternative F (restoration of seagrass beds on degraded lagoon bottoms) should be evaluated further because it creates a highly valued habitat in a potentially expendable habitat. Further, this alternative could provide for large-scale use of fine materials. The steps in a further evaluation include: evaluation of monitoring results of the experiment conducted in 1994 by the Corps of Engineers; acquisition and interpretation of data on degraded lagoon bottom habitats to determine conditions and potential benefits/impacts of sediment placement; and, if the results of these steps are promising, construction of a demonstration project that would include the assessment of relatively coarse-grained caps to reduce turbidity, and sediment pore-water studies to evaluate the extent of seagrass toxicity as measured by ammonia, sulfides, and total organic carbon. The evaluation of Alternative F also would provide information of value in assessment of Alternative E.

- Alternative G (creating new dredged material islands with levee material from existing islands) should be evaluated further because it could provide an innovative way of creating diverse and high-value bird island habitat. Specifically, the main habitat platform would utilize fluid muds, and these would be confined and capped by coarse materials taken from existing islands, especially islands that are in need of sculpturing. The appropriate steps for advancing this alternative include: an inventory of existing islands to identify reshaping needs and the potential for mining (e.g. through soil cores); preliminary designs to provide a better understanding of how various habitat types could be created using predominantly fine material; and an assessment of potentially suitable lagoon bottoms for placement of new islands. If the results of these steps are promising, a small-scale demonstration project could be constructed. The evaluation of Alternative G would provide information of value in assessment of Alternatives H and I.

Collectively, the three evaluations should address the most important issues that have been identified: transportation impacts; habitat loss; habitat benefits; and the practicality of innovative designs for using fine materials. At this time, we recommend no further action on the remaining two alternatives: Alternative A (beach nourishment) and Alternative D (creation of tidal flats).

Summary of recommendations. The following alternatives have been identified for further study: 1) ODMDS placement; 2) nourishing of existing islands, 3) nourishing of washovers, 4) restoration of seagrass beds on degraded lagoon bottoms; and 5) creation of new dredged material islands with levee material from existing islands. Unlike the current study which relied on previously collected data, the next evaluations will need to include field studies of potentially impacted habitats, along with relatively detailed conceptual designs, so that they will result in more site-specific and project-specific conclusions. Viable alternatives could then be tested by demonstration projects. In our judgment, the highest demonstration priority is to test the viability of creating useful habitat by confining fluid muds. If it is determined that fluid muds cannot be beneficially used to a substantial degree, then the choice (if dredging continues) will be between conventional placement and export of the material (e.g. to an ODMDS or upland site).

6. REFERENCES

Adair, S.E., Moore, J.L., and Onuf, C.P. 1994. Distribution and status of submerged vegetation in estuaries of the upper Texas coast. Wetlands, 14:110-121.

Andrews, P.B. 1964. Serpulid reefs, Baffin Bay, southeast Texas. In Depositional Environments, South-Central Texas Coast, Gulf Coast Assoc. of Geol. Societies, Field Trip Guidebook, p. 101-120.

Bacak-Clements. 1997. *Threatened and endangered species for counties bordering the Laguna Madre,* south of Corpus Christi, TX. U.S. Fish and Wildlife Service, Corpus Christi, TX.

Battelle. 1997. Identifying, planning, and financing beneficial use projects using dredged material. Beneficial Use Manual. Prepared for the U.S. Environmental Protection Agency, EPA Contract No. 68-C2-0134, WA 3-135, by Battelle Seattle Research Center, Seattle, WA and Battelle Ocean Sciences, Duxbury, MA.

Boyle, E. A. et al. 1984. Trace metals and radium in the Gulf of Mexico: an evaluation of river and continental shelf sources. Earth Planet. Sci. Lett. 69:69-87.

Breuer, J. P. 1962. An ecological survey of the lower Laguna Madre of Texas, 1953-1959. Pub. Inst. Marine Science, Vol. 8, 153-183.

Britton, J. C., Morton, B. 1989. Shore ecology of the Gulf of Mexico. University of Texas, Austin, Tex. 387 pp.

Brown, C.A. and Kraus, N.C. 1997. Environmental monitoring of dredging and processes in the Lower Laguna Madre, Final Report. Conrad Blucher Institute for Surveying and Science, 3Texas, Texas A&M University, Corpus Christi, TX.

Brown, C. A., N. C. Kraus, K. H. Dunton, J. E. Kaldy, T. A. Schleman and J. W. Tunnell, Jr. 1997. Environmental monitoring of dredging and processes in Lower Laguna Madre, Texas: Final Report, Year 1. TAMU-CC-CBI-96-01. U.S. Army Corps of Engineers, Galveston, Tex. 118 pp. + Appendices.

Brown, L. F., Jr., J. L. Brewton, T. J. Evans, J. H. McGowen, W. A. White, C. G. Groat and W. L. Fisher. 1980. Environmental geologic atlas of the Texas coastal zone--Brownsville-Harlingen area. Bureau of Economic Geology, University of Texas, Austin, Tex. 140 pp., 9 sheets.

Brown, L. F., Jr., J. L. Brewton, J. H. McGowen, T. J. Evans, W. L. Fisher and C. G. Groat. 1976. Environmental geologic atlas of the Texas coastal zone--Corpus Christi area. Bureau of Economic Geology, University of Texas, Austin, Tex. 123 pp., 9 sheets.

Brown, L. F., Jr., J. H. McGowen, T. J. Evans, C. G. Groat and W. L. Fisher. 1977. Environmental geologic atlas of the Texas coastal zone--Kingsville area. Bureau of Economic Geology, University of Texas, Austin, Tex. 131 pp., 9 sheets.

Cifuentes, L., K. Dunton, P. Eldridge and J. Morse. 1997. The effect of dredge deposits on the distribution and productivity of seagrasses: an integrative model for Laguna Madre. 114 pp.

Coste, R. L. and M. K. Skoruppa. 1989. Colonial waterbird rookery island management plan for the south Texas coast. Center for Coastal Studies, Corpus Christi State University.

Diaz, A. and M. Kelley. 1994. Subsidized destruction: the Gulf Intracoastal Waterway and the Laguna Madre. Texas Center for Policy Studies. Austin, TX.

Dunton, K. H. 1994. Seasonal growth and biomass of the subtropical seagrass *Halodule wrightii* in relation to continuous measurements of underwater irradiance. Mar. Biology, 120:479-489.

____. 1998. Personal communication from Ken Dunton, University of Texas Marine Science Institute, Corpus Christi, TX, to Steve Anderson, Lee Wilson and Associates, Santa Fe, NM.

EHA. 1998. Laguna Madre, Texas, contaminant assessment. Prepared for U.S. Army Corps of Engineers, Galveston District, Galveston, TX, and Lee Wilson and Assoc., Santa Fe, NM, by Espey, Huston & Associates, Inc., Austin, TX.

____. 1997. Laguna Madre data reduction and analyses water and sediment quality and tissue chemistry. Espey, Huston & Associates, Inc., Austin, TX. 20+ pp.

____. 1996. Laguna Madre data reduction and analyses, water and sediment quality and tissue chemistry. Prepared for U.S. Army Corps of Engineers, Galveston District, by Espey, Huston & Associates, Inc. Austin, TX.

EPA. 1994. Environmental impact statement for general New Source NPDES permit for oil and gas extractions in the Territorial Seas of the Gulf of Mexico off Texas and Louisiana. U.S. Environmental Protection Agency, Region 6, Dallas, TX.

GBA. 1997. Alternative dredging and placement cost estimates. Laguna Madre, Port Isabel to Mudflats, Vicinity of Mile 660, GIWW stations 45 + 000 to 65 + 000. Prepared for Espey, Huston &

Associates, Inc., Austin, TX, and the U.S. Army Corps of Engineers, Galveston, TX, by Gahagan & Bryant Associates, Inc., Houston, TX.

Gosselink, J. G., C. L. Cordes, and J. W. Parsons. 1979. An ecological characterization study of the Chenier Plain coastal ecosystem of Louisiana and Texas. U. S. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-78/9 through 78/11. 3 vols.

Gunter, G. 1967. Vertebrates in hypersaline waters. Contributions in Marine Science, 12: 230-241.

Hahl, D. C., and K. W. Ratzlaff. 1973. Chemical and physical characteristics of water in estuaries of Texas, October 1968 - September 1969. Texas Water Development Board, Austin. Rep. 117. 97 pp.

Hayes, M. O. 1965. Sedimentation on a semiarid wave-dominated coast (south Texas) with emphasis on hurricane effects. Ph.D. Dissertation, Univ. of Texas, Austin, 350 p.

Hedgpeth, J. W. 1967. Ecological aspects of the Laguna Madre, a hypersaline estuary. Pages 408-419 in G. H. Lauff, ed. Estuaries. Am. Assoc. Adv. Sci. Pub. 83.

Herber, J.P. 1981. Holocene sediments under Laguna Madre, Cameron County, Texas. University of Texas, Master's Thesis, 664 p.

LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran, M. J. Mac. 1995. Our living resources. U.S. Dept. of the Interior, National Biological Service, Washington, DC.

Lind, W.B. and K. W. Ratzlaff. 1976 (and in other years). Chemical and physical characteristics of water in estuaries of Texas, October 1973-September 1974. Report by the U.S. Geological Survey to the Texas Water Development Board.

LWA. 1998. Characterization of dredged material, Laguna Madre, Texas. Prepared for the U.S. Environmental Protection Agency, Region 6, Dallas, Texas, by Lee Wilson and Associates, Santa Fe, New Mexico and Coastal Environments, Inc., Baton Rouge, Louisiana.

McLellan, N. 1997. Personal communication to L. Nakashima from N. McLellan, U.S. Army Corps of Engineers, Galveston, TX.

McMahan, C. A. 1968. Biomass and salinity tolerance of shoal grass and manatee grass in lower Laguna Madre, Texas. J. Wildlife Management, 32(3): 501-506.

Militello, A, Kraus, N.C., Kite II, R. D. 1997. Environmental monitoring of dredging and processes in the Upper Laguna Madre. Final Report, Year 1, Conrad Blucher Institute for Surveying and Science, 3Texas, Texas A&M University, Corpus Christi, TX.

NOAA. 1995. Intracoastal waterway - Texas: Laguna Madre, Chubby Island to Stover Point including the Arroyo Colorado. U.S. Department of Commerce, National Oceanographic and Atmospheric Administration. Nautical Chart 11303. 18th ed. 1:40,000. Nautical chart map. Washington, D. C. 1 map.

Onuf, C. P. 1996. Seagrass responses to long-term light reduction by brown tide in Upper Laguna Madre, Texas: distribution and biomass patterns. Mar. Ecol. Prog. Series. 138: 219-231.

____. 1996a. Biomass patterns in seagrass meadows of the Upper Laguna Madre, Texas. Bulletin of Mar. Sci., 58:404-420.

____. 1994. Seagrasses, dredging and light in Laguna Madre, Texas, U.S.A. Estuarine, Coastal and Shelf Science 39:75-91.

Presley et al. 1988. Chapter 5: Marine chemistry. In: Phillips, N. W. and B. M. James, eds. Offshore Texas and Louisiana marine ecosystems data synthesis, Volume II: Synthesis report. Prepared by Continental Shelf Associates, Inc., for the U.S. Department of the Interior Minerals Management Service, New Orleans, LA. MMS 88-0067.

Pullich, W. 1998. Personal communication from Warren Pulich, Texas Parks and Wildlife Department, Austin, TX, to Steve Anderson, Lee Wilson and Assoc., Santa Fe, NM.

Quammen, M. L. and C. P. Onuf. 1993. Laguna Madre: seagrass changes continue decades after salinity reduction. Estuaries 16: 303-311.

Roop, S., and Dickinson, R. 1993. Economic impacts of a closure of the GIWW along the Laguna Madre. Texas Transportation Institute, Texas A&M University, College Station, Texas.

Schoellhammer, D. H. 1995. Sediment resuspension mechanisms in Old Tampa Bay, Florida. Estuarine, Coastal and Shelf Science, 40: 603-620.

Sheridan, P. 1996. Temporal and spatial effects of open water dredged material disposal on habitat utilization by fishery species in Laguna Madre, Texas (Year 1). Southeast Fisheries Science Center, National Marine Fisheries Service, Galveston, Tex. 9+ pp.

Shew, D. M., R. H. Baumann, T. H. Fritts, and L. S. Dunn. 1981. Texas barrier islands region Ecological characterization: environmental synthesis papers. U. S. Fish and Wildlife Service, Biological Services Program, Washington, D. C. FWS/OBS-81/32. 413 pp.

Shiller, A. M. and E. A. Boyle. 1983. Trace metals in the plume of the Mississippi River. EOS Trans. Am. Geophys. Un.l 64:1,021 (abstract).

Simmons, E. G. 1957. An ecological survey of the upper Laguna Madre of Texas. Publ. Inst. Mar. Sci. Univ. Tex. 4(2): 156-200.

Smith, N. P. 1978. Intracoastal tides of upper Laguna Madre, Texas. Texas Journal of Science, XXX(1): 85-95.

Texas. 1997. http://www.state.tx.us/agency/agencies.mtml.

TNRCC. 1996. Fiscal year 1997 annual work plan. CCBNEP-10. Texas Natural Resource Conservation Commission, Austin, Tex. 56 pp.

___. 1995. Fiscal year 1996 annual work plan. CCBNEP-04. Texas Natural Resource Conservation Commission, Austin, Tex. 67 pp.

___. 1994. 1994 regional assessment of water quality in the Rio Grande Basin, including the Pecos River, the Devils River, the Arroyo Colorado and the Lower Laguna Madre. Watershed Management Division, Texas Natural Resource Conservation Commission.

TPWD. 1997. Nature - Endangered and threatened species. Texas Parks and Wildlife Department, Austin, TX.

Tunnell, J. W., Jr., Q. R. Dokken, E. H. Smith and K. Withers. 1996. Current status and historical trends of the estuarine living resources within the Corpus Christi Bay National Estuary Program Study Area: Volume 1. CCBNEP-06A. Texas Natural Resources Conservation Commission, Austin, Tex. 543 pp.

TWC. 1990. The State of Texas water quality inventory. 10th Edition, 1990. Texas Water Commission. Section 305(b) report. LP 90-06. Austin, TX.

USACE. 1987. Beneficial uses of dredged material. Engineer Manual 1110-2-5026. U.S. Army Corps of Engineers, Washington, DC.

____. 1983. Dredging and dredged material disposal. Engineer Manual No. 1110-2-5025. U.S. Army Corps of Engineers, Washington, DC.

USFWS. 1997. Threatened and endangered species list for counties bordering the Laguna Madre south of Corpus Christi, TX. Facsimile. U. S. Fish and Wildlife Service. Corpus Christi, Texas. 3 Pages.

Wanless, H.R. 1974. Intracoastal sedimentation. In Stanley, D. J. and Swift, D. J. P., eds., The New Concepts Of Continental Margin Sedimentation, Am. Geol. Inst., Short Course Notes, Key Biscayne, Florida.

Ward, L. G., W. M. Kemp, and W. R. Boynton. 1984. The influence of waves and seagrass communities on suspended particulates in an estuarine embayment. Marine Geology, 59: 85-103.

Weise, B. R. and W. A. White. 1980. Padre Island National Seashore: a guide to the geology, natural environments, and history of a Texas Barrier Island. Guidebook 17. Bureau of Economic Geology, University of Texas, Austin, Tex. 94 pp. + map.

White, W. A., T. R. Calnan, R. A. Morton, R. S. Kimble, T. G. Littleton, J. H. McGowen, H. S. Nance and K. E. Schmedes. 1989. Submerged lands of Texas, Kingsville area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bureau of Economic Geology, University of Texas, Austin, Tex. 137 pp.

___. 1986. Submerged lands of Texas, Brownsvillle-Harlingten area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bureau of Economic Geology, University of Texas, Austin, Tex. 138 pp., 6 plates.

___. 1983. Submerged lands of Texas, Corpus Christi area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands. Bureau of Economic Geology, University of Texas, Austin, Texas. 154 pp.

Withers, K. 1994. The relationship of macrobenthic prey availability to shorebird use of the blue-green algal flats in the upper Laguna Madre. Ph.D. dissertation, Texas A&M University, College Station, Texas.

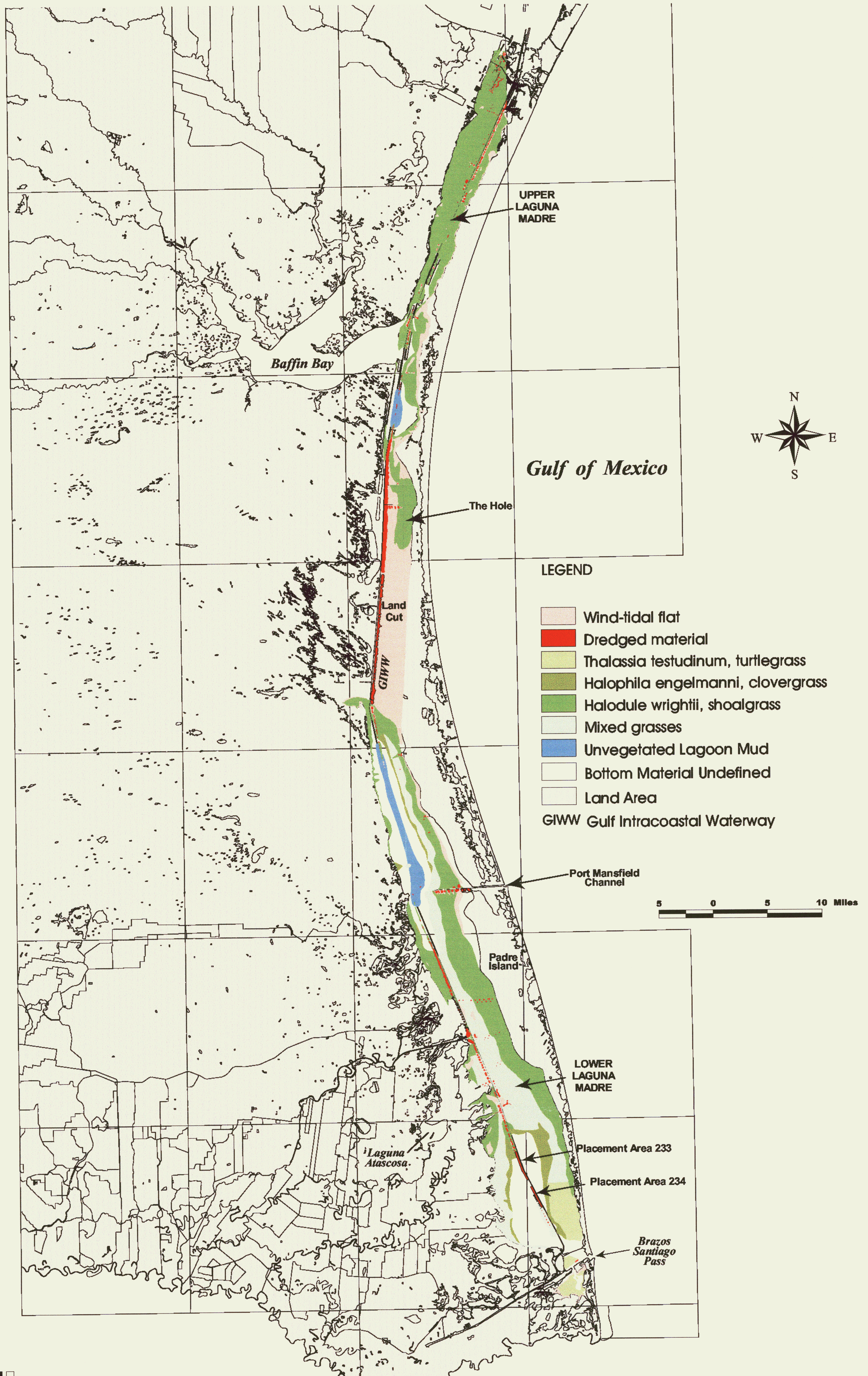


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Figure 2 - 5

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Distribution of Seagrasses and Dredged Material in Laguna Madre

Ref: Chris Onuf, 1988 (USFWS)
U.S.G.S. 30x60 min. DLG